The endurance shuttle walk: a new field test for the assessment of endurance capacity in chronic obstructive pulmonary disease

S M Revill, M D L Morgan, S J Singh, J Williams, A E Hardman

Abstract

***Background*—The purpose of this study was to develop an externally controlled, constant paced field walking test to assess endurance capacity in patients with chronic obstructive pulmonary disease (COPD). There were four objectives: (1) to develop a protocol; (2) to compare treadmill and shuttle walk tests of endurance capacity; (3) to examine the repeatability of the endurance shuttle walk test; and (4) to compare the sensitivity to pulmonary rehabilitation of endurance and incremental shuttle walk tests.**

***Methods*—The test was designed to complement the incremental shuttle walk test (ISWT) using the same 10 m shuttle course and an audio signal to control pace. The intensity of the field endurance test was related to a percentage of each patient's maximum field exercise performance assessed by the ISWT. A number of cassette tapes were prerecorded with a range of audio signal frequencies to dictate walking speeds between 1.80 and 6.00 km/h. In the first limb of the study 10 patients with COPD (mean (SD) forced expiratory volume in one second (FEV_1) 1.0 (0.36) l, 35% predicted) performed three endurance shuttle walk tests (ESWTs) and three treadmill endurance tests. The walking speeds were calculated to elicit 75%, 85%, and 95% of each patient's maximum ISWT performance for the field tests and measured peak oxygen consumption for the treadmill tests. In a separate group of patients the repeatability of the ESWT at an intensity of 85% of the ISWT performance was evaluated. Finally, the ESWT (at the 85% intensity) and the ISWT were performed at the start of a five week control period and at the start and end of a seven week pulmonary rehabilitation programme in 21 patients with COPD (mean FEV_1 0.80 (0.18) l).**

***Results*—The mean (SE) times achieved during the ESWT were 13.1 (2.3), 10.2 (2.5), and 5.3 (1.7) min for the walks at 75%, 85%, and 95% intensities, respectively. Patients tended to walk for longer on the treadmill than during the field tests at all intensities, but there were no significant differences between the end of test heart rates or Borg ratings of breathlessness or perceived exertion. Following one practice ESWT at the 85% intensity, the mean difference and limits of agreement (2SD) between tests 2 and 3 was +15 (42) s (p>0.05). There was no significant change in performance on either test following the five week control period prior to rehabilitation. Following rehabilitation the ESWT duration increased by 160 (24)% and the ISWT distance increased by 32 (11)% (effect sizes 2.90 and 0.41, respectively).**

***Conclusions*—The ESWT was simple to perform, acceptable to all patients, and exhibited good repeatability after one practice walk. The test showed major improvement following rehabilitation and was more sensitive to change than the field test of maximal capacity.**

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Keywords: endurance shuttle walk test; chronic obstructive pulmonary disease; field exercise testing

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Most activities of daily living represent exertion at submaximal exercise levels, so a measure of the ability to sustain a given submaximal exercise (endurance capacity) is an important component of the assessment of disability. In patients with chronic obstructive pulmonary disease (COPD) field walking tests are used as simple assessments of disability. The 12 and six minute field walk tests are self-paced[1 2] and probably assess a combination of peak performance and endurance capacity. Their semi-standardised nature contributes a degree of variability in the performance of the tests,[3 4] and the imposition of a time limit constrains the validity of the tests as true measures of endurance capacity. A standardised field test of endurance capacity using constant walking speeds, external regulation of pace, and in which all patients experience a similar level of exercise intensity relative to their individual maximal capacity does not exist.

The development of a standardised, open ended field assessment of endurance capacity is desirable for the following reasons: (1) to overcome some of the difficulties associated with the existing timed walk tests—for example, variability in the patient selected walking speeds and in the operation of such tests between centres and studies; and (2) field tests are more flexible, accessible, and less costly than laboratory based tests.

The incremental shuttle walk test (ISWT)[5] uses a 10 m course and the walking speed is externally controlled by signals from an audio cassette. Since this has been found to be a sat-

Table 1 Mean (SD) patient data

	Group A (n = 10)	Group B (n = 11)	Group C (n = 21)
M:F	9:1	3:8	10:11
FEV_1 (l)	1.01 (0.36) (35 (4)% pred)	0.79 (0.21) (34 (4)% pred)	0.80 (0.18) (35 (8)% pred)
FVC (l)	2.92 (0.55) (81 (20)% pred)	2.0 (0.80) (68 (14)% pred)	2.06 (0.90) (68 (20)% pred)
FEV_1/FVC (%)	34 (6)	40 (10)	45 (17)
Borg score (at rest)	1.3 (0.9)	1.6 (1.0)	1.9 (1.1)
Age (years)	63.7 (5.5)	66.3 (5.0)	69 (6.6)
Weight (kg)	69.7 (12.6)	68.0 (11.6)	70.8 (15.1)

FEV_1 = forced expiratory volume in one second; FVC = forced vital capacity.
Group A performed the protocol development and comparison of treadmill and shuttle endurance walks, group B performed the repeatability limb, and group C performed the intervention limb.

isfactory method to standardise walking speed, the proposed test used a similar approach—that is, pre-recorded audio signals on a cassette tape and a 10 m shuttle course. The ISWT has been shown to produce a maximal response in patients with COPD[6] so, in order to relate the walking speed of the field endurance shuttle walk test (ESWT) to a field measure of maximal exercise capacity, all patients performed an ISWT. Endurance capacity has been defined as the ability to sustain a high proportion of individual maximal oxygen uptake.[7] We therefore investigated three endurance intensities which were related to 75%, 85%, and 95% of individual maximal capacity in order to establish a test of sufficient intensity to be practicable, yet not too lengthy for the patient and operator.

The aims of this study were: (1) to develop a shuttle walk test of endurance capacity; (2) to compare treadmill and shuttle walk tests of endurance capacity; (3) to examine the repeatability of the endurance shuttle walk test; and (4) to compare the sensitivity to pulmonary rehabilitation of endurance and incremental shuttle walk tests.

Methods

PATIENTS

Three groups of patients were recruited and they took part in the four limbs of the study as follows: group A (n = 10) participated in the development of the ESWT protocol and in the comparison of the treadmill and shuttle endurance tests; group B (n = 11) participated in the repeatability limb of the study; and group C (n = 21) was recruited to compare the sensitivity to pulmonary rehabilitation of endurance and incremental shuttle walk tests. Patients in group A were recruited from the outpatient respiratory clinics whilst patients in groups B and C were recruited from the waiting list for the pulmonary rehabilitation programme. Ten patients were common to both the repeatability and sensitivity limbs of the study.

COPD was diagnosed according to the British Thoracic Society guidelines[8] and all patients were recruited on the basis of willingness to participate, evidence of moderate to severe airflow obstruction (FEV_1 <60% predicted), and self-reported exercise limitation due to breathlessness. Patients with cardiological, neurological, or locomotor disorders that limited exercise performance were excluded. All patients (with the exception of two) were on regular inhaled steroid treatment and all used inhaled bronchodilators. Three patients were receiving low dose oral steroids (prednisolone) and 12 patients were on diuretic therapy. Three patients recruited to the intervention limb (group C) were receiving domiciliary oxygen therapy for at least 15 hours per day and six patients were using oxygen for symptomatic relief only. There were no alterations to any medication during the study, although patients were instructed to use their inhaled bronchodilator within one hour of their study appointment time.

The study was approved by the district ethics committee and was fully explained before written informed consent was obtained from all participants. Height and weight were recorded at the start and weight was rechecked periodically during the study period. The FEV_1 was measured at every visit using a wedge bellows spirometer (Model R, Vitalograph Ltd, Bucks, UK) according to the BTS/ARTP guidelines.[9] Baseline breathlessness at rest was rated by Borg scales.[10] Prediction values for static lung function variables were obtained from the European guidelines[11] and prediction values for maximal exercise were obtained from the paper by Jones.[12] The characteristics of the patients are shown in table 1.

Table 2 Range of pre-recorded endurance walking speeds

Level	Warm up speed (km/h)	Endurance speed (km/h)	Time/10 m shuttle (s)
1	1.50	1.78	20.3
2	1.50	2.09	17.3
3	1.50	2.44	14.8
4	1.50	2.72	13.3
5	1.50	3.00	12.0
6	2.40	3.27	11.0
7	2.40	3.60	10.0
8	2.40	3.79	9.5
9	2.40	4.11	8.8
10	2.40	4.36	8.3
11	2.40	4.65	7.8
12	2.40	4.97	7.3
13	2.40	5.14	7.0
14	2.40	5.54	6.5
15	2.40	5.76	6.3
16	2.40	6.00	6.0

For each level the warm up speed was played for 100 s and the faster speed for the endurance test was played for 20 min.

MEASUREMENTS

Development of the endurance shuttle walk test

A series of signal frequencies were recorded onto a number of cassette tapes to provide an audio cue for constant walking over a range of speeds (table 2). Each tape started with a one minute calibration signal to ensure correct operation of the tape and cassette player followed by standardised instructions to the patient. A "warm up" slower pace, which lasted for approximately 100 s, preceded the endurance speed to enable the patient to practise

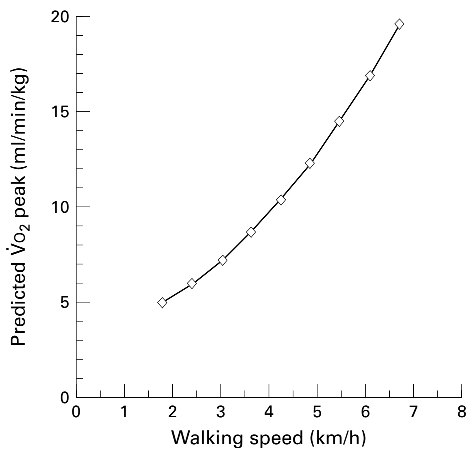

Figure 1 Incremental shuttle walking speeds and predicted oxygen consumption ($\dot{V}O_2$peak).

walking around the shuttle course. At the sound of a triple signal and a brief recorded message the signal frequency changed to the quicker endurance test speed which remained constant for 20 minutes.

The 10 m shuttle course was demarcated by cones on a quiet flat hospital corridor. Patients were instructed to walk along the course, turning around the cones at either end in time with the audio signals from the cassette player. The instructions were to continue walking until too tired or breathless to continue. For practical purposes we used a cut off time at 20 minutes, but patients were unaware of any time limit and were discouraged from estimating how long they had been walking.

To determine endurance exercise intensity, three intensities were investigated for the developmental limb of the study. In order to relate the walking speed of the field endurance tests to a percentage of individual maximum exercise capacity in the field an ISWT was performed. This enabled an approximate value for the peak oxygen consumption ($\dot{V}O_2$peak) to be predicted[6] and used as a reference point to determine the speed of the ESWT for each patient. The regression equation used to predict the $\dot{V}O_2$peak from the ISWT distance was described by Singh *et al*[6] and derived from a group of patients with a wide range of impairment (FEV_1 range 0.5–3.11 l). Values for $\dot{V}O_2$ equivalent to 75%, 85%, and 95% of the predicted $\dot{V}O_2$peak were calculated and the corresponding walking speeds interpolated from a graph which related shuttle walking speeds to predicted $\dot{V}O_2$peak (fig 1). A cassette tape with signal frequencies closest to the derived speeds was selected from the bank of pre-recorded tapes. For example, patient 2 achieved 320 m in the ISWT which gave a predicted $\dot{V}O_2$peak of 12.2 ml/min/kg (regression equation: 4.19 + 0.025 (distance)[6]). The walking speeds which related to $\dot{V}O_2$ values of 9.1, 10.4, and 11.6 ml/min/kg (75%, 85%, and 95% of the predicted $\dot{V}O_2$peak) were read from the graph (fig 1) and ESWT tape levels 9, 10 and 12 were selected (table 2).

The heart rate was recorded during all field tests using a short range telemetry device (Sports tester PE3000, Polar Electro). The device consisted of a transmitter in a belt worn around the chest and a receiver worn around the wrist. Breathlessness and perceived exertion were rated from Borg scales[10] immediately at the end of all the field exercise tests. The reasons for stopping exercise and the endurance exercise times were recorded.

Treadmill tests of endurance capacity

Cardiorespiratory measurements were made continuously during all of the treadmill tests using a computerised breath by breath exercise test system (OxyconBeta, Erich Jaeger). An ear oximeter (Biox 3700e, Ohmeda) provided simultaneous measurement of arterial oxygen saturation (SaO_2). Arterialised ear lobe capillary blood samples were taken at rest, at peak incremental treadmill exercise, and at the end of the 85% endurance treadmill test for the measurement of blood gas tensions and pH. Additional ear lobe samples were taken at four minutes after exercise for the measurement of blood lactate concentration. Breathlessness and perceived exertion were rated immediately at the end of the treadmill exercise and the reasons for stopping exercise were also recorded.

In order to relate the intensity of the treadmill endurance tests to a percentage of the patient's maximum exercise capacity on a treadmill an incremental, symptom limited test was performed to establish individual values of $\dot{V}O_2$peak. On a separate occasion a submaximal treadmill test was also performed in order to identify the relationship between oxygen uptake and treadmill walking speed for each patient. This submaximal test consisted of three different walking speeds of four minutes duration with a short rest period between each. The $\dot{V}O_2$ was measured during each stage and a graph of $\dot{V}O_2$ and the corresponding speed was plotted for each patient. The walking speeds which related to 75%, 85%, and 95% of the measured $\dot{V}O_2$peak for each patient were interpolated from their own individual graph. The three individualised walking speeds were used for the treadmill endurance tests.

The treadmill endurance tests were conducted in a manner similar to the field tests. The patients were instructed to walk for as long as possible. A slower "warm up" speed which lasted for 100 s was incorporated at the start of the tests and a 20 min time limit was imposed for the faster endurance speed. The patients remained unaware of the time limit; all clocks in the laboratory were turned out of sight and patients were not informed of how long they had been walking.

Repeatability of the endurance shuttle walk test

The results from the developmental limb of the study showed that the ESWT at the 95% intensity provoked a response similar to a maximum test for most of the patients, whilst 40% of the patients reached the 20 minute limit of the 75% ESWT. Thus, the most suitable endurance intensity for the field test, in terms of duration and patient acceptability, was the 85% intensity. This level of the ESWT was

Table 3 Patients' responses at the end of the endurance shuttle walk tests

	Time (min)	HR (beats/min)	Borg ratings BS	PE
75% ESWT	13.1 (2.3)	117 (5)	3.9 (0.4)	13.5 (0.6)
85% ESWT	10.2 (2.5)	121 (6)	4.5 (0.6)	13.6 (0.9)
95% ESWT	5.3 (1.7)*	126 (8)†	5.0 (0.5)	14.3 (0.7)

HR = heart rate; BS = breathlessness; PE = perceived exertion.
*Significantly different from 85% and 75% tests (p<0.05).
†Significantly different from 75% test (p<0.05).
Values are mean (SE) measured at the end of each ESWT.

examined in the repeatability and sensitivity limbs of the study.

Sensitivity of the endurance and incremental shuttle walk tests

Patients in group C performed the endurance and the incremental shuttle walk tests at the start of a five week control period and at the start and end of a seven week outpatient pulmonary rehabilitation programme. The programme had educational and aerobic exercise components, and patients attended the hospital physiotherapy department for two hour classes twice weekly. The educational component consisted of interactive talks covering a variety of topics and a folder containing notes for the patient's future reference. The exercise training component consisted of a circuit of thoracic mobility and peripheral muscle strength training exercises in the physiotherapy gym (one hour per week) and a daily, home based walking programme. The walking training consisted of free walking—that is, not restricted to any circuit or equipment—for an individually prescribed time. The time was based on a treadmill endurance test performed during the initial pulmonary rehabilitation assessment. Patients kept a diary of walking time and were encouraged to increase the time throughout the seven weeks. Patients with oxygen desaturation (<86%) during the initial assessment performed the exercise training with portable oxygen.

STUDY DESIGN

Group A completed the developmental limb of the study which involved 10 separate visits. Following the incremental tests to establish individual maximal exercise capacity on the treadmill and in the "field", three treadmill endurance tests and the three ESWTs (relating to 75%, 85%, and 95% of maximal exercise capacity) were presented in randomised order on separate occasions. For the repeatability limb of the study patients in group B made three visits to the hospital over a period of 15 days. At the first visit the ISWT was performed and after a rest period of at least 40 minutes an ESWT at 85% intensity was performed. The 85% ESWT was repeated during visits 2 and 3. For the sensitivity limb of the study patients in group C made four separate visits. Following a pre-study familiarisation visit at which practice shuttle tests were performed, the ESWT at the 85% intensity and an ISWT were measured at the start of a control period (no change in treatment) and at the start and the end of the pulmonary rehabilitation programme.

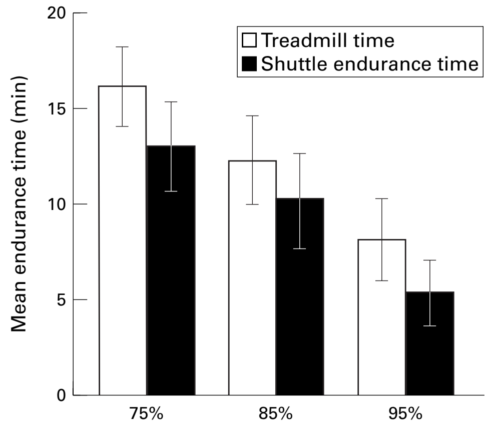

Figure 2 Mean (SE) shuttle and treadmill endurance times.

STATISTICAL ANALYSIS

Summary data are expressed as mean (SD) unless otherwise stated, and a 5% level of significance was adopted throughout. Relationships between variables were examined using the Pearson product moment correlation coefficient (*r*) and the method of least squares was used for any regression analysis. The Student's *t* test was used to examine the difference between two correlated means and analysis of variance (ANOVA) used for multiple comparisons. The Scheffe post hoc test was used to determine where significant differences occurred. The results of the Borg ratings were subject to appropriate non-parametric analysis.

Results

DEVELOPMENT OF THE ESWT

All patients in group A completed the developmental limb with an average time between visits of 10 (4) days. The endurance capacity was defined as the duration of walking at the set endurance speed. The mean walking speeds for the three ESWTs were 3.8 (0.72), 4.1 (0.71), and 4.4 (0.71) km/h for the 75%, 85%, and 95% tests, respectively. There was a progressive decrease in the endurance times as the intensity increased (table 3). One patient completed 20 minutes in all three ESWTs. As a precaution this patient repeated the ISWT to ensure a peak performance had been achieved but the result was identical. There was a trend for the Borg ratings for breathlessness to increase as the endurance intensity increased, but there were no significant differences between ratings. The same was true for the ratings of perceived exertion (table 3).

There was no relationship between the FEV_1 and the endurance times. There was a moderate and statistically significant relationship between the 75% and the 85% endurance times (r = 0.83, p<0.05), but this was influenced by the number of patients attaining the externally imposed 20 minute time limit in both tests.

The mean distance walked during the ISWT was 313 (96) m with a peak heart rate of 123 (20) beats/min. The mean duration of the ISWT was 345(156) s. The mean Borg ratings at the end of the ISWT were 4.9 (1.9) for

Table 4 Mean (SE) responses to treadmill tests to determine $\dot{V}O_2$peak and endurance capacity

Test	$\dot{V}O_2$peak (ml/min/kg)	$\dot{V}E$ (l/min)	HR (beats/min)	Vt (ml)	fR (breaths/min)	RER	BS	PE
Endurance								
75%	12.1 (0.5)	33.4 (3.1)	112 (7)	1287 (104)	26.6 (2.1)	0.87 (0.01)	4.1 (0.7)	13.2 (0.9)
85%	13.4 (0.9)	37.2 (4.2)	114 (6)	1394 (126)	26.8 (1.7)	0.90 (0.02)	4.5 (0.5)	14.0 (0.8)
95%	15.1 (1.0)*	40.5 (3.4)*	122 (7)†	1444 (103)*	28.5 (2.1)	0.92 (0.02)	5.8 (0.7)*	15.3 (0.7)*
Incremental	15.5 (1.2)	42.1 (4.0)	120 (6)	1614 (158)	28.2 (1.8)	0.91 (0.02)	5.5 (0.5)	15.4 (0.6)

$\dot{V}O_2$peak = oxygen consumption; $\dot{V}E$ = ventilation; HR = heart rate; Vt = tidal volume; fR = respiratory rate; RER = respiratory exchange ratio; BS = breathlessness; PE = perceived exertion.
Measurements were from the final minute of each endurance test and the symptom limited incremental treadmill test.
*Significantly different from 75%.
†Significantly different from 75% and 85% ($p<0.05$).
Incremental $\dot{V}O_2$peak = 1.09 (0.08) l/min.

breathlessness and 13.3 (1.9) for perceived exertion. Breathlessness was identified as the main cause of exercise termination during the ISWT.

TREADMILL ENDURANCE TESTS AND COMPARISON WITH SHUTTLE TESTS

The mean walking speeds for the three treadmill endurance tests were 3.4 (1.0), 4.0 (1.1), and 4.7 (1.2) km/h for the 75%, 85%, and 95% tests, respectively. The mean (SE) times were 16.2 (2.1), 12.3 (2.3), and 8.1 (2.2) min for the 75%, 85%, and 95% tests, respectively (fig 2). Although patients tended to walk for longer on the treadmill than around the shuttle course, there were no significant differences between times. There were wide differences in some patients, however, and subsequently there were no significant relationships between the treadmill and field test times except for the 75% tests ($r = 0.68$, $p<0.05$). This relationship was, however, influenced by the number of patients who attained the externally imposed 20 minute limit. There were no significant differences between the heart rate at the end of the test and the Borg ratings at comparable field and treadmill endurance levels.

The mean values of SaO_2 at the end of the treadmill endurance exercise were 93.0 (2.1)%, 92.4 (3.1)%, and 91.7 (2.4)% for the 75%, 85%, and 95% tests, respectively. The end of test values for $\dot{V}O_2$, ventilation ($\dot{V}E$), and heart rate showed a progressive increase at each level of endurance intensity (table 4). There was wide variability in the pattern of the $\dot{V}O_2$ responses at the same endurance intensities. Four patients attained a steady state in their $\dot{V}O_2$ during the 75% test and two patients had a rapid increase to reach a peak response at this level (final $\dot{V}O_2 \geqslant \dot{V}O_2$peak). The remaining patients had a gradual increase in $\dot{V}O_2$. Five patients attained a peak response during the 95% test and two patients achieved a steady state. The mean percentages of individual $\dot{V}O_2$peak achieved during the final minute of each endurance test were 81 (16)%, 87 (13)%, and 97 (11)% for the 75%, 85%, and 95% tests, respectively.

The main reasons for terminating exercise during the 75% and 85% tests were attainment of the 20 minute limit or leg fatigue and general fatigue for both the ESWT and the treadmill endurance tests. Breathlessness was cited more often during the 95% endurance tests.

For comparison purposes the results of the symptom limited incremental treadmill test are also shown in table 4. The $\dot{V}O_2$peak of the group was lower than the predicted normal value (55%) and there was a moderate heart rate reserve (73% predicted). There was a degree of oxygen desaturation with the SaO_2 falling from 95.4 (1.5)% at rest to 91.5 (2.4)% during the incremental maximum test. The mean fall was 3.9 (2.6)%. There was also a fall in the PaO_2, but little change in the $PaCO_2$. The blood gas analysis and lactate concentrations are shown in table 5.

There was no relationship between baseline FEV_1 measurements and the treadmill times. A significant relationship was found between the fall (Δ) in SaO_2 and the 85% endurance time ($r = 0.72$, $p<0.025$). The relationship between the fall in SaO_2 and the 75% treadmill time was of borderline significance ($r = 0.62$, $p = 0.06$). There were significant relationships between the end of test field and treadmill heart rates ($r = 0.90$, 0.76, and 0.73, respectively, for the 95%, 85%, and 75% tests, $p<0.025$; fig 3).

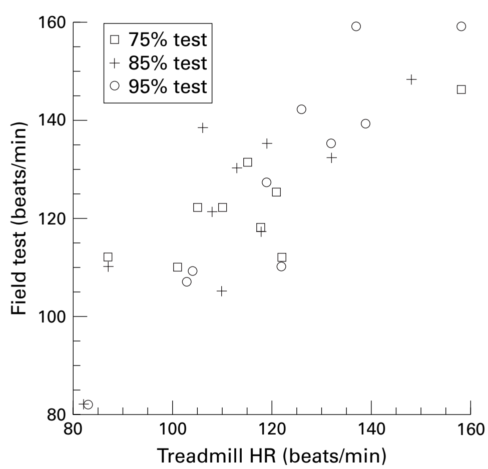

Figure 3 Individual heart rates (HR) at the end of the shuttle and treadmill endurance tests.

Table 5 Mean (SE) blood gas tensions and blood lactate concentration following incremental and 85% endurance treadmill tests

	PaO_2 (kPa)	$PaCO_2$ (kPa)	pH	Lactate (mmol/l)
Incremental				
Rest	9.88 (0.32)	4.84 (0.06)	7.423 (0.007)	0.39 (0.14)
Peak	8.03 (0.24)	4.87 (0.18)	7.391 (0.012)	1.22 (0.52)
85%				
Rest	10.42 (0.44)	4.74 (0.10)	7.426 (0.007)	0.41 (0.12)
Peak	8.50 (0.42)	4.92 (0.13)	7.386 (0.009)	1.34 (0.56)

PaO_2, $PaCO_2$ = arterial oxygen and carbon dioxide tensions.
Values are for rest and peak exercise, except for blood lactate concentration which was measured four minutes after exercise.

Table 6 Repeatability of the 85% endurance shuttle walk test (n = 11)

Visit	Time (s)†	Distance (m)†	HR (beats/min)†	Borg ratings BS†	Borg ratings PE†
1	251 (120)*	214 (101)*	108 (17)	4.6 (2.0)	12.7 (1.9)
2	310 (171)	262 (137)	107 (16)	4.4 (1.6)	12.6 (2.1)
3	325 (158)	274 (130)	103 (16)	4.5 (1.7)	12.9 (2.7)
		Time (s)‡		Distance (m)‡	
Test 2 vs 1		59.5 (22.4) (95% CI 9.7 to 109.2)		47.5 (18.4) (95% CI 6.6 to 18.4)	
Test 3 vs 1		74.3 (18.8) (95% CI 32.5 to 116.1)		60.3 (16.2) (95% CI 24.1 to 96.5)	
Test 3 vs 2		14.8 (6.3) (95% CI 0.6 to 28.9)		12.8 (4.9) (95% CI 1.9 to 23.6)	

HR = heart rate; BS = breathlessness; PE = perceived exertion.
*Signficantly different from tests 2 and 3 ($p<0.05$).
†Mean (SD) values for three 85% ESWTs performed over a 15 day period.
‡Mean (SE) and 95% confidence intervals for the differences between repeat tests.

Table 7 Endurance (ESWT) and incremental shuttle walk tests (ISWT) before and after rehabilitation (n = 21)

	Time (s)	Distance (m)	HR (beats/min)	BS	PE
ESWT					
Control	265 (34)	228 (30)	113 (4)	4.3 (0.4)	12.5 (0.5)
Start rehabilitation	270 (31)	237 (31)	112 (4)	4.2 (0.3)	12.1 (0.3)
	5 (−20 to 30)	9 (−12 to 30)			
End rehabilitation	674 (86)*	571 (78)*	116 (4)	3.7 (0.3)*	11.6 (0.4)*
	404 (264 to 544)	334 (211 to 450)			
ISWT					
Control	–	175 (17)	113 (4)	5.1 (0.4)	12.7 (0.3)
Start rehabilitation	–	178 (20)	106 (4)	4.6 (0.4)	13.9 (0.5)
		3 (−15 to 22)			
End rehabilitation	–	215 (20)*	111 (4)	3.9 (0.3)*	12.1 (0.4)*
		36 (11 to 61)			

*Significantly different from start ($p<0.05$).
Mean (SE) time, distance walked, heart rate (HR) at the termination of exercise, and Borg breathlessness (BS) and perceived exertion (PE) at the start of the control period and at the start and end of rehabilitation. The mean differences (95% confidence intervals) between the start and end of the control period (visit 3–2), and the start and end of the rehabilitation programme (visit 4–3) are also shown.

REPEATABILITY OF THE ESWT

A summary of the repeat data for the 85% ESWT is presented in table 6. Each patient completed three tests within 15 days. All patients showed an improvement in the ESWT performance after one test and eight patients had an improvement after two tests. There was a strong relationship between tests 2 and 3 ($r = 0.995$) with no significant differences between these two tests. The mean differences and 95% confidence intervals are also shown in table 6 and the differences between tests 2 and 3 are illustrated in fig 4.

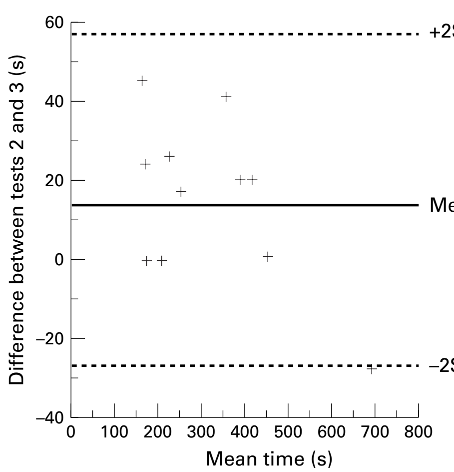

Figure 4 Differences in 85% shuttle endurance time between tests 2 and 3 (n = 11).

SENSITIVITY TO REHABILITATION OF THE ESWT AND ISWT

Four patients had a fall in oxygen saturation to <86% during the initial practice ISWT and received ambulatory oxygen for all subsequent tests. In addition, these patients also received ambulatory oxygen during the exercise training component of the rehabilitation programme. The mean resting $Sa{O_2}$ for the whole group was 94.5 (1.5)%. At the end of the initial familiarisation ISWT the $Sa{O_2}$ was 90.8 (3.7)% and the mean fall was 3.7 (3.0)%.

The mean duration of the control period was 5 (1.2) weeks and the mean endurance walking speed at 85% intensity was 3.02 (0.75) km/h. There was no significant change in performance on the ESWT at the start and end of the control period, the mean (SE) difference in time spent walking being +5 (11.9) s and the difference in distance walked was +9.3 (10.3) m ($p>0.05$). Similarly, there was no significant change in performance on the ISWT (mean difference +3.0 (9.0) m).

All the patients with the exception of patient 10 had an improvement in the ESWT at the end of the rehabilitation course. Prior to rehabilitation the maximum time achieved by any single patient during the ESWT was 709 s (11 min 49 s). Following rehabilitation three patients completed 1200 s (20 min) and four patients achieved >17 min. The response to the ISWT was more variable with 10 patients having an improvement of ⩾30 m and in 11 patients the ISWT distance was within 29 m of their pre-rehabilitation test. There were significant improvements in both the ESWT and ISWT for the whole group. The mean percentage improvement in endurance capacity was 160 (110)% and for the ISWT was 32 (50)%. There was a large effect size for the ESWT (2.9) and a moderate effect size for the ISWT (0.41). A summary of the walking test results for both the ESWT and ISWT are shown in table 7 and fig 5.

Only one patient did not show an improvement in the ESWT following rehabilitation (patient 10). A slight decrease in the endurance capacity was measured (436 s at the start of rehabilitation and 399 s at the end). To eliminate the possibility of a spurious result the post-rehabilitation ESWT was repeated at a separate visit. The results were within four seconds (399 s and 395 s). Additionally, there was minimal improvement in the ISWT. This patient died suddenly three weeks after completing the course.

There were significant improvements in the Borg ratings for dyspnoea and perceived exertion following rehabilitation for both the ESWT and the ISWT (table 7). The reasons for the termination of endurance exercise did not change appreciably during the control period. Following rehabilitation, fewer patients identified dyspnoea (8 vs 13, $p = 0.07$) and more patients identified tiredness as the main symptom following the ESWT (5 vs 1, $p<0.05$). The frequencies of the reasons for exercise termination are shown in fig 6. The main reason for termination of the ISWT was

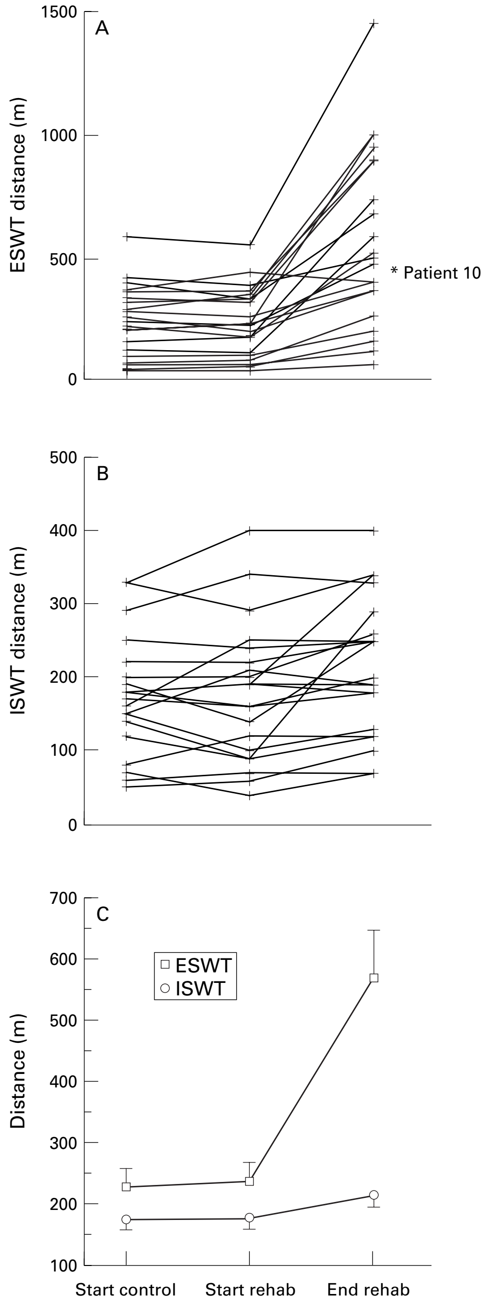

Figure 5 Individual (A) endurance and (B) incremental shuttle walking distances and (C) mean (SE) distances for both tests at the start of the control period and at the start and end of rehabilitation.

dyspnoea and this remained unchanged following rehabilitation.

There were no significant changes in the peak heart rate response following both the ESWT and the ISWT during the control period and following rehabilitation. The mean (SE) heart rate responses at equivalent endurance times before and after rehabilitation were 111 (4.0) and 111 (3.9), respectively.

Discussion

We have developed an endurance field test with an externally controlled, constant walking speed to achieve standardisation of exercise intensity and to give patients the opportunity to sustain exertion until limited by symptoms. The test showed good repeatability after one practice walk and was sensitive to change following pulmonary rehabilitation. The adaptation of the ISWT format has shown that standardisation of constant walking speed is achievable, and the intensity of exercise may be determined individually from the peak field performance measured during the ISWT. The test was acceptable to all the patients in the study, it was simple to perform, required minimal inexpensive equipment, and might be used in any quiet enclosed space of >10 m.

DEVELOPMENTAL LIMB

At each relative intensity the group achieved longer endurance times on the treadmill with slightly lower heart rates than with the equivalent ESWT, which suggests that treadmill walking provoked less physiological stress. The differences in response to the test modalities probably reflect a number of fundamental differences between treadmill and free walking. There is lower energy expenditure on the treadmill as a result of the belt assisting the backward movement of the foot and there are differences in shoe to ground friction and step impact.[13] There is likely to be higher energy expenditure during the shuttle walk as a result of turning the corners of the circuit compared with walking in a straight line on the treadmill. However, the heart rate responses provoked by the ESWT were similar to those achieved on the treadmill, with significant relationships between comparable levels of endurance. This finding supports the use of the ESWT to provoke a similar cardiac response to that produced at a comparable intensity on the treadmill.

The patients were given no indication of how long they had been walking and, to avoid setting targets, were not informed of the 20 minute limit. In this sense the ESWT was open ended, in contrast to the six or 12 minute walk tests which are time limited and self-paced. Previous studies have shown that knowledge of the imposed time limit of a test influences pacing and the distance covered.[3] Such findings emphasise the non-standardised nature of the timed walk tests which rely on individual judgement of pace and a self-imposed work rate. Whilst it may be argued that self-pacing is a valuable skill to be learnt by severely limited patients,[14] the imposition of a stated time limit constrains the validity of the tests as true measures of endurance capacity. In addition, the adoption of a habitual walking pace will impose a natural limit to any increase following an intervention and may mask the full beneficial effect of any treatment.[15] Any variability in work rate was avoided with the ESWT where the speed was externally imposed, so the test is likely to be a more rigorous measure of longitudinal change than self-paced tests.

A short endurance test is desirable in terms of practical application and for the wider margin for change following an intervention. However, four patients completed three minutes or less during the 95% test whilst four patients completed the full 20 minutes of the 75% ESWT. The results from this study suggest that

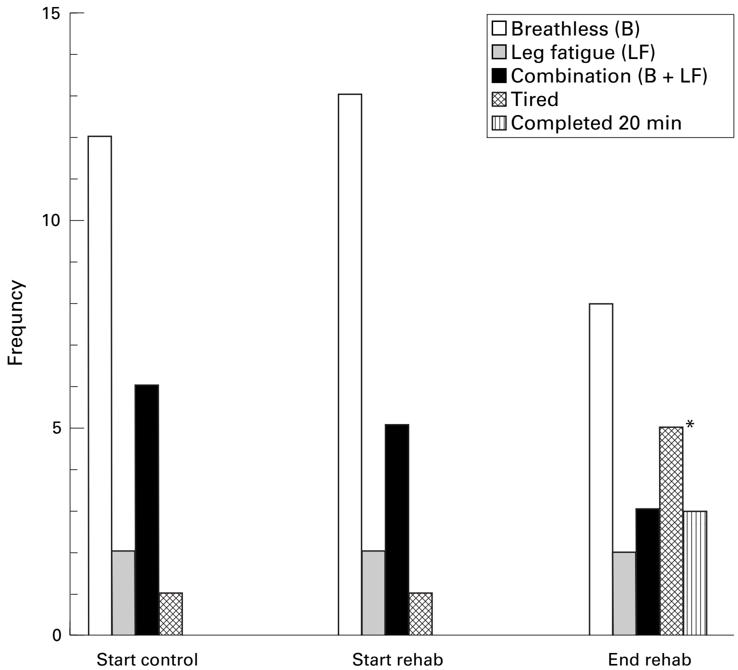

*Figure 6 Frequency of occurrence of symptoms at the termination of shuttle endurance exercise. (*p <0.05).*

an intensity related to 85% of maximum capacity is a suitable compromise. Furthermore, the 95% ESWT provoked a maximum performance in some patients, as shown by the higher heart rate response than with the ISWT. This is also supported by the higher $\dot{V}O_2$ during the treadmill tests where the 95% test produced a peak response in five patients and a higher heart rate in six patients. All reasonable precautions were taken to ensure that patients attained their maximum during the incremental tests. However, there is less time to attain a steady state during the shorter stages of an incremental test. In a study by Matthews *et al*[16] a constant work rate test at 75% of the maximum work load provoked a higher heart rate and $\dot{V}O_2$ than the peak values measured during an incremental test in patients with COPD and in a normal control group. These findings suggest that an incremental test may not always be the best method of obtaining the highest cardiorespiratory values for some patients.

The purpose of the submaximal treadmill test was to establish the relationship between treadmill speed and $\dot{V}O_2$ for each patient to enable the calculation of endurance speeds as a percentage of the $\dot{V}O_2$peak. The model was largely successful for the 95% and 85% treadmill tests, but the $\dot{V}O_2$ achieved at the end of the 75% treadmill test was much higher than the target level (mean value 81%). This finding raises a number of issues. The maximal exercise capacity may be so reduced that lower intensity exercise will engage a high proportion of the maximal capacity, and even minimum exertion will elicit a high energy expenditure. However, 75% of $\dot{V}O_2$peak is a relatively high intensity, even if in absolute terms the walking speed may be slow or moderate. The energy requirement for walking on the level at 3 km/h is estimated at 2–4 kcal/min, or less than 1 l/min of oxygen in healthy individuals.[13] This level of oxygen consumption is close to the $\dot{V}O_2$peak measured in the patients in this study. The ability of the patients to exercise at high intensities relative to $\dot{V}O_2$peak supports the findings of others[17 18] where high intensity training and testing have been used in rehabilitation programmes. The provocation of high proportions of individual maximum capacity by relatively low absolute work loads has implications for exercise prescription and training intensity in this patient group.

REPEATABILITY

A positive improvement in 85% ESWT was measured with each successive performance of the test, and suggested a diminishing learning effect in the test performance. Although the first test was performed on the same day as the ISWT, there was a rest period of at least 40 minutes between tests so the development of undue tiredness was unlikely. The third test improved the ESWT duration by an average of only 15 s compared with an increase of 60 s following the first test. Thus, reasonably good test repeatability was established following one practice walk, though imprecision in the limits of repeatability may be present as a result of the small sample size. However, the mean (SE) difference of +15 (6) s (distance = 13 (5) m) compares favourably with a repeatability of +41 (18) m for the 12 minute walk test,[1] and +2 (10) m for the ISWT.[5] In routine clinical use the ISWT, the practice ESWT, and actual ESWT may be required on the same day, in which case rest periods of at least 40 minutes should be allowed between tests. The smaller mean difference between the tests carried out at the start and end of the five week control period of the intervention limb suggests that the learning effect diminished with time, whilst greater individual variability is suggested from the wider confidence interval (50 s).

SENSITIVITY TO REHABILITATION

The magnitude of improvement in the ESWT was far greater than the improvement in the ISWT (effect size 2.90 vs 0.41). With the exception of one patient, the improvements in the ESWT were large (minimum improvement 30%) and consistent. These findings support the contention that tests of endurance capacity exhibit greater sensitivity to change than tests of maximum capacity following rehabilitation in patients with COPD.

The relatively greater improvement in the ESWT emphasised that endurance capacity is likely to be more amenable to exercise training in this patient group where the pathophysiology of COPD may limit improvements in the maximum capacity. Following rehabilitation, three patients attained the 20 minute limit of the ESWT and four patients achieved more than 17 minutes. Only three of these seven patients had significant improvements in the ISWT which suggests that possible improvements in maximum aerobic capacity cannot wholly explain the changes in endurance exercise for some patients. The variable changes in the ISWT contrast with the large and consistent improvements in the ESWT and emphasise the need to examine endurance capacity when pulmonary rehabilitation is undertaken.

The improvements in the 85% ESWT indicated that the changes in endurance capacity were not confined to the training intensity (all the patients confirmed that the ESWT speed was faster than they would normally walk). A study which closely examined training intensity in patients with severe COPD found that most of the patients were unable to achieve a target training intensity of 80% maximum work rate on a cycle ergometer.[19] However, there were significant improvements in exercise tolerance following the rehabilitation and evidence of physiological adaptation to training. The current study and others[19] suggest that useful improvements can be achieved with moderate training intensities; however, in severely limited patients with reduced $\dot{V}O_2$peak, low and moderate absolute work rates are likely to engage a high proportion of the $\dot{V}O_2$peak.

The purpose of predicting a value for the $\dot{V}O_2$peak from the ISWT is to provide a reference for the maximum performance achieved during field exercise. Equally, the individual maximum walking speed might offer a suitable reference from which the intensity of endurance exercise can be derived. In the intervention limb of the study the mean ESWT walking speed for the group was 3.02 (0.75) km/h which equated to 83 (5)% of the maximum speed achieved during the initial ISWT. Whether the post-training assessments should be conducted at pre-training intensities is an important question and forms a natural adjunct of further research to the current study. In the case of patients achieving the 20 minute limit, a simple reassessment at the next endurance walking speed on the ESWT tape may form a practical solution which warrants further investigation.

Most patients improved their walking duration with similar or reduced ratings of dyspnoea and perceived exertion. There was no change in the heart rate response which suggests there was no cardiac training effect. However, the improvements in endurance capacity and lowered sense of perceived exertion would support a hypothesis of enhanced mechanical efficiency. Improved skill of performance and coordination will lead to improved efficiency and have a sparing effect on $\dot{V}O_2$. Such a mechanism would suggest more efficient use of existing capacity and may partly explain why many of the patients had an increased endurance capacity without concurrent improvements in maximal capacity.

Only one patient did not improve following the rehabilitation (patient 10). The patient died within a few weeks of completing the course and details of the sudden death suggested it was of cardiac origin. The lack of improvement suggested that other covert clinical problems may have acted to negate any therapeutic effects from the rehabilitation.

LIMITATIONS OF THE STUDY

The sample size for the repeatability limb of the study was small and this may have resulted in some imprecision in the limits of agreement. However, the repeatability following one practice walk was at least as good as other field measures of exercise. The stability of the ESWT over shorter and longer periods—for example, within a day and over 6–8 weeks—requires further investigation in addition to the establishment of the minimum clinical important difference. The ESWT is more complex to administer at the initial testing stage, requiring the performance of the ISWT to enable the endurance speed to be calculated. In addition, the derivation of the speed might be simplified by using a percentage of the maximum ISWT speed achieved. However, we would always recommend the measurement of both maximal and endurance capacity to assess disability and the effects of rehabilitation in COPD. During the intervention limb we used each patient as their own control rather than having a separate parallel control group. Furthermore, we did not use a sham rehabilitation programme to control for placebo effects. Whilst there is no consensus for the type, frequency, and intensity of exercise training in this patient group, many of the published studies report a variety of approaches. We feel the benefits of the exercise training component of pulmonary rehabilitation have already been firmly established following a review of 14 randomised controlled trials and the publication of evidence based guidelines.[20]

In summary, the ESWT was sensitive to pulmonary rehabilitation, the test amplified the training induced changes, and large improvements were seen in most patients. The changes suggest that the rehabilitation acted to optimise the use of residual functional capacity, whilst its impact on maximal capacity was more variable where improvement may be limited by the extent of pulmonary impairment. The developmental study highlighted the differences between treadmill walking and free walking around the shuttle circuit. Although the heart rate responses were similar, patients walked for longer on the treadmill, suggesting lower physiological stress. The ESWT benefits from standardised walking speeds and allows the same exercise challenge to be repeated longitudinally. It is simple to perform, requiring only minimal equipment, and has good repeatability over the short and medium term. This study has demonstrated large improvements in the ESWT following pulmonary rehabilitation, and endorses the need to examine endurance capacity where this intervention is used in the clinical management of patients with COPD.

The endurance shuttle walk test is available on cassette tape. The tapes and instruction leaflet may be obtained from Dr S M Revill, Department of Respiratory Medicine, Glenfield Hospital, Leicester LE3 9QP, UK.

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