DM Seminar

Exercise testing in Respiratory disease

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Introduction

- Exercise is important part of sports performance, part of healthy lifestyle, physical therapy, diabetes, depression, rehabilitation, physiotherapy, and weight loss
- Aerobic and anaerobic (isometric or resistance) exercises
- Aerobic exercise uses large muscle mass and causes increase significantly, oxygen demand by the contracting muscles and delivery by the cardiopulmonary system.
- The aim of aerobic exercise is to increase cardiopulmonary and oxygen extraction by the skeletal muscles. Running, cycling, swimming, and walking are examples for aerobic exercise mode

Introduction

- Anaerobic exercise, which includes strength and resistance training, increases strength and muscle mass, as well as improves bone density example-weightlifting training, isometric training, eccentric training, interval training

Hemodynamic and muscular function changes following exercise training

Variables	Aerobic exercise	Resistance exercise
Maximal oxygen uptake	Increase	Unchanged
Maximal minute ventilation	Increase	unchanged
Cardiac output	Increase	Unchanged
Heart rate rest and maximal	Decrease	Increase or unchanged
Stroke volume rest and Maximal	Increase	Unchanged
Systolic blood pressure rest	Unchanged or decrease	Increase
Diastolic blood pressure	Unchanged or decrease	Increase
Mitochondrial capacity	Increase	Unchanged
Mitochondrial size and number	Increase	Unchanged
Basal metabolic rate	Increase	Unchanged
Anaerobic Capacity	Increase	Increase
Lactate tolerance	Increase	Increase
Capillary density	Increase	Unchanged
Muscle mass	Unchanged or decrease	Increase
Strength	Unchanged	Increase
Skeletal muscle hypertrophy	Unchanged or decrease	Increase

Exercise tests

- **Field tests**
- Incremental shuttle walk test
- Endurance shuttle walk test
- 6 min walk test
- The Harvard step test
- The Cooper 12min/walk run test

- **Laboratory tests**
- Incremental exercise test
- High-intensity constant work-rate exercise tests

Field Tests

Why field tests is required?

- Exercise capacity (peak exercise capacity, functional exercise capacity or endurance)
- Factors limiting exercise performance (dyspnoea, subjective fatigue, musculoskeletal limitations)
- Response to an intervention

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Equipment required for conduct of field walking tests

- At least one chair, positioned at one end of the walking course
- A validated scale to measure dyspnoea and subjective fatigue
- Sphygmomanometer for blood pressure measurement
- Pulse oximeter and Stopwatch
- Pre-measured marks along the track/corridor
- Access to oxygen and telephone in case of an emergency
- An emergency plan
- Portable supplemental oxygen if required by patient to perform exercise test
- Clipboard with reporting sheet and pen

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Test location and Staffing

- Dedicated exercise testing room (along a quiet course, physiotherapy gym)
- Comfortable temperature (air conditioning if available)
- Rapid, appropriate response to an emergency is possible and crash cart is available
- Oxygen, sublingual nitroglycerine and salbutamol (metered dose inhaler or nebuliser)
- Telephone or other means of calling for help should be available in case of emergency
- Assessor performing the test should be certified in cardiopulmonary resuscitation (Basic Life Support certification)

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Indications

- **Functional status**
- Diffuse parenchymal lung disease
- Pulmonary Hypertension
- Bronchiectasis
- COPD
- Cystic fibrosis

- **Predictor of morbidity and mortality**
- Heart failure
- COPD
- Diffuse parenchymal lung disease
- Primary pulmonary hypertension

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Indications

- **Pre treatment and post treatment comparisons**
- Lung transplantation
- Lung resection
- Lung volume reduction surgery
- Pulmonary rehabilitation

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Absolute contraindications

- Uncontrolled Asthma
- Acute pulmonary embolus
- Thrombosis of lower extremities
- Suspected dissecting aneurysm
- Acute respiratory failure
- Acute noncardiopulmonary disorder (i.e. infection, renal failure, thyrotoxicosis)
- Acute myocardial infarction (3–5 days)
- Unstable angina
- Uncontrolled arrhythmias causing symptoms or haemodynamic compromise
- Active endocarditis, myocarditis or pericarditis
- Uncontrolled heart failure
- Symptomatic severe aortic stenosis

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Relative contraindications

- Moderate stenotic valvular heart disease
- Severe untreated arterial hypertension at rest (200 mmHg systolic, 120 mmHg diastolic)
- High-degree atrioventricular block
- Hypertrophic cardiomyopathy
- Significant pulmonary hypertension
- Advanced or complicated pregnancy
- Electrolyte abnormalities
- Orthopaedic impairment that prevents walking

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Patient Preparation

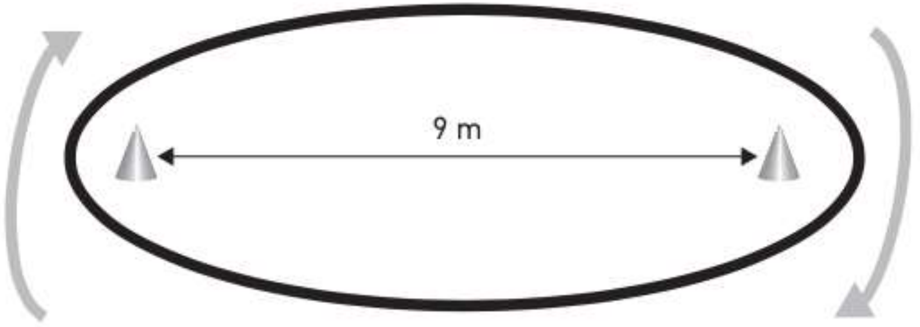
- Wear comfortable clothing and appropriate shoes for walking
- Use their usual walking aids during test and this should be documented on the assessment form
- Avoid vigorous exercise within 2 h of beginning the test
- Take usual medications before the test
- If any pulmonary function tests is to be performed, this should occur prior to exercise testing
- For example if Spirometry is performed then patients should rest for at least 15 min before commencing an exercise test

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Protocol: Incremental shuttle walk test

- Course is 10 m in length and is identified for the patient by two cones with an inset of 0.5 m from either end), thus avoiding abrupt changes in direction
- Beginning of the test the instructions are played to the patient from an audio recording

FIGURE 1 Course layout for the incremental and endurance shuttle walk tests. Cones are inset 0.5 m from either end to avoid abrupt changes in direction.



European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Protocol：Incremental shuttle walk test

- Initially slow speed
- Each minute speed increases
- Tests starts in 15 sec
- Level – 1 (triple beep 4 sec)
- 20 sec each 10 meter shuttle
- Each minute record heart rate and SpO2
- Patient walks until too breathless or not able to keep up beeps
- Beeps at regular interval
- First beep – turn around the cone at one end
- Second beep – turn around the cone at other end

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Protocol :Incremental shuttle walk test

- Each single beep – end of a shuttle
- Each triple beep – increase the walking speed
- Easier at starting
- Harder at end

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Termination : Incremental shuttle walk test

- **Patient**: indicates that they are unable to continue excessive dyspnoea ,fatigue (commonly leg fatigue) or pain (knee/hip/low back pain)
- **Operator** : **says patient is not fit to continue**
- Patient fails to reach the cone/marker in the time allowed time. This is defined as patient being 0.5 m away from the cone when the bleep sounds on a second successive 10-m length
- When the patient is just outside the 0.5m marker they are advised to increase their speed of walking; if the patient fails to do so then the test is terminated
- SpO_2 falls below 80%

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Recording

- Heart rate and Spo2
- Calculate the distance walked, in metres
- Record the reason for termination

- Tests done twice
- Repeat on same day 30min apart
- Another day but within one week time

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Shuttle Walk Test Recording Form

Unit:

Designation:

Date:

ID:

First name:

Last name:

D.O.B. (dd/mm/yyyy)

Diagnosis:

Medication taken today	Dose	How many hours prior to testing?

Supplemental oxygen: yes/no
Flow rate:
Device:
Method carried:

Walking aid: yes/ no (specify)

Level:		1	2	3	4	5	6	7	8	9	10	11	12
ISWT	1												
	2												

		ISWT1	ISWT2			ESWT1	ESWT2
				Date/ Time:			
Date/ Time:				Speed/ level:			
Start	Dyspnoea			Start	Dyspnoea		
	HR				HR		
	SpO_2				SpO_2		
Distance (m):				Time (seconds):			
End	Dyspnoea			End	Dyspnoea		
	Exertion				Exertion		
	HR				HR		
	SpO_2				SpO_2		
Recovery	Dyspnoea			Recovery	Dyspnoea		
	Exertion				Exertion		
	HR				HR		
	SpO_2				SpO_2		
Reason for termination				Reason for termination:			

ESWT calculation:

Comments:

Print: Signature:

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

Incremental shuttle walk test

Distance Walked (m)	Speed km/h	ESWT level
10	1.78	1
20	1.78	1
30	1.78	1
40	1.78	1
50	1.78	1
60	1.78	1
70	2.09	2
80	2.09	2
90	2.44	3
100	2.44	3
110	2.44	3
120	2.72	4
130	2.72	4
140	3	5
150	3	5
160	3	5
170	3.27	6
180	3.27	6
190	3.27	6
200	3.6	7
210	3.6	7
220	3.6	7

Distance Walked (m)	Speed km/h	ESWT level
230	3.6	7
240	3.6	7
250	3.79	8
260	3.79	8
270	4.11	9
280	4.11	9
290	4.11	9
300	4.36	10
310	4.36	10
320	4.36	10
330	4.65	11
340	4.65	11
350	4.65	11
360	4.65	11
370	4.65	11
380	4.97	12
390	4.97	12
400	4.97	12
410	4.97	12
420	4.97	12
430	5.14	13
440	5.14	13

Distance Walked (m)	Speed km/h	ESWT level
450	5.14	13
460	5.54	14
470	5.54	14
480	5.54	14
490	5.54	14
500	5.54	14
510	5.54	14
520	5.54	14
530	5.76	15
540	5.76	15
550	5.76	15
560	5.76	15
570	6	16
580	6	16
590	6	16
600	6	16
610	6	16
620	6	16
630	6	16
640	6	16
650	6	16
660	6	16

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

ORIGINAL ARTICLE

Comparing peak and submaximal cardiorespiratory responses during field walking tests with incremental cycle ergometry in COPD

- Subjects n=24 , moderated to severe COPD
- Completed four sessions > 24 hr apart
- Each session either two 6-min walk tests, incremental shuttle walk tests, endurance shuttle walk tests using standardized protocols, or a single CET, wearing a portable gas analysis unit) which included measures of heart rate and arterial oxygen saturation (SpO2)
- Primary aim: to compare peak and submaximal cardiorespiratory responses during the field walk tests with cycle ergometry test patients of COPD

Respirology (2012) 17, 278–284

Comparing peak and submaximal cardiorespiratory responses during field walking tests with incremental cycle ergometry in COPD

Table 3 Peak (end-test) cardiorespiratory responses

	6MWT	ISWT	ESWT	CET
$\dot{V}O_2$ (mL/min)	1168 ± 344	1227 ± 310	1232 ± 368	1186 ± 314
$\dot{V}CO_2$ (mL/min)	1009 ± 270†	1036 ± 327†	1060 ± 342*	1173 ± 350
Respiratory exchange ratio	0.87 ± 0.11†	0.84 ± 0.10†	0.86 ± 0.12†	0.99 ± 0.17
$\dot{V}_E$ (L/min)	41 ± 17†	43 ± 15†	44 ± 16*	48 ± 17
Tidal volume (L)	1.39 ± 0.46	1.35 ± 0.42	1.36 ± 0.46	1.45 ± 0.46
Heart rate (beats/min)	128 ± 17	127 ± 14	130 ± 15	128 ± 19
SpO_2 (%)	88 ± 5†	88 ± 5†	88 ± 5†	95 ± 4

Respirology (2012) 17, 278–284

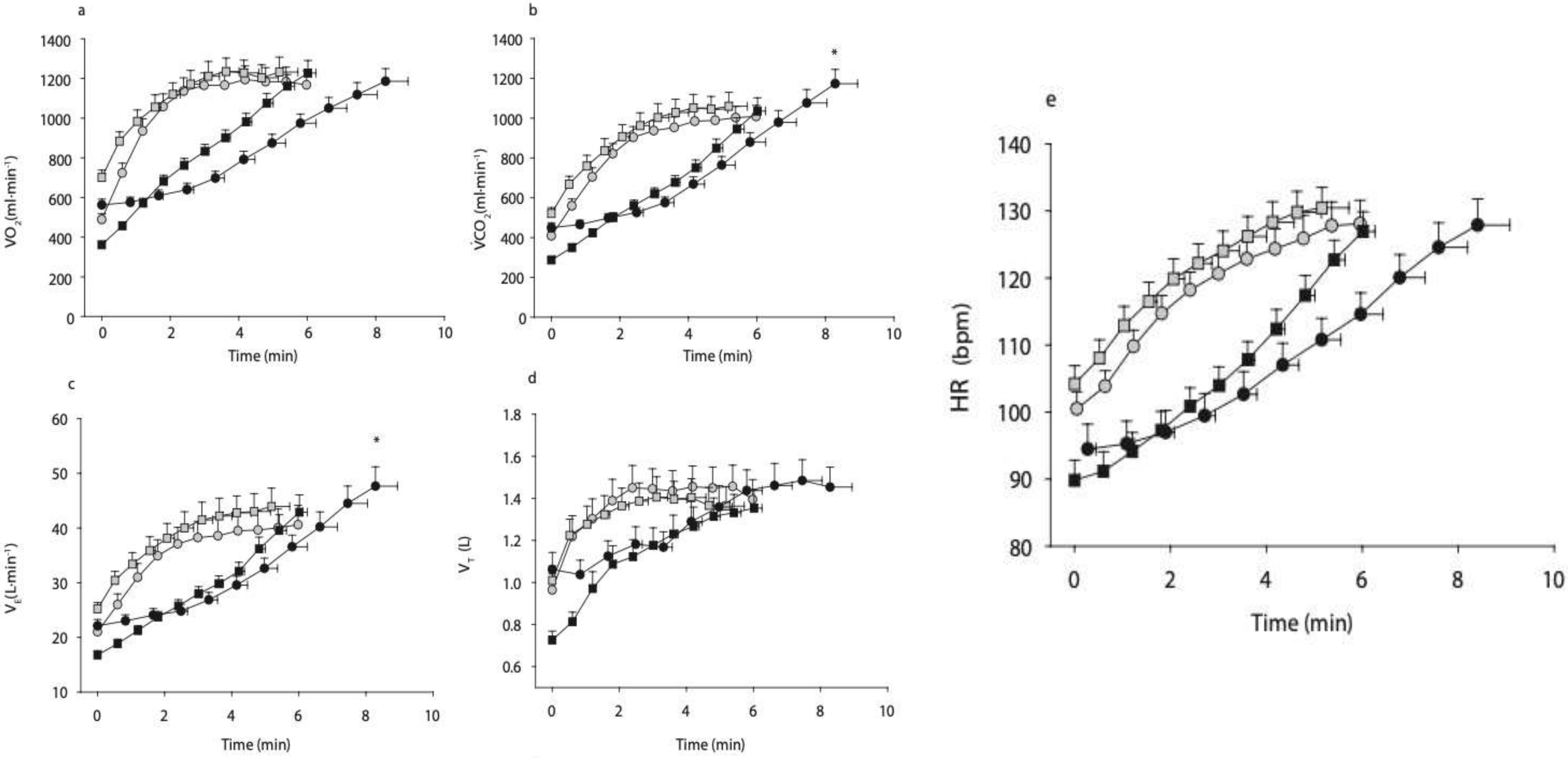


Figure 1 Data are mean and standard error. All participants contribute to each data point. Figures are patterns of response for; (a) rate of oxygen uptake ($\dot{V}O_2$), (b) rate of carbon dioxide output ($\dot{V}CO_2$), (c) minute ventilation ($\dot{V}_E$), (d) tidal volume (V_T), (e) heart rate (HR) and (f) arterial oxygen saturation measured via pulse oximetry (SpO_2) for each test. ●, cycle ergometry test; ◯, 6-min walk test; ■, incremental shuttle walk test; ◻, endurance shuttle walk test; * $P < 0.05$ for difference between cycle ergometry with all other tests.

Respirology (2012) 17, 278–284

Shuttle Walking Test as Predictor of Survival in Chronic Obstructive Pulmonary Disease Patients Enrolled in a Rehabilitation Program

- 416 patients performed an ISWT before entering a 7-week outpatient pulmonary rehabilitation program
- Follow up for 4.5 yrs
- Risk of dying increased markedly when ISWT was lower than 170 m (RR - 2.84, 95% CI: 2.05-3.93)

J Cardiopulm Rehabil Prev. 2010 Nov-Dec;30(6):409-14

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Cochrane Database of Systematic Reviews

Pulmonary rehabilitation for chronic obstructive pulmonary disease (Review)

McCarthy B, Casey D, Devane D, Murphy K, Murphy E, Lacasse Y

Change in maximal exercise (Incremental Shuttle walk test (ISWT)) Distance metres Follow-up: median 12 weeks	Median change = 1 metre	Mean maximal exercise (incremental shuttle walk test) in the intervention groups was **39.77 metres higher** (22.38 to 57.15 higher)	694 (8 studies)

Cochrane Database Syst Rev. 2015 Feb 23;2015(2)

Minimum clinically important improvement for the incremental shuttle walking test

S J Singh,[1,2] P W Jones,[3] R Evans,[1] M D L Morgan[1]

- 372 patients (205 men) performed an ISWT before and after a 7-week outpatient pulmonary rehabilitation programme
- Responses: better, slightly better, about the same, slightly worse or worse; each response was assigned a numerical value from 1 to 5
- Slightly better - 47.5 m (95% CI 38.6 to 56.5)
- Better - 78.7 m (95% CI 70.5 to 86.9)
- Same - 18.0 m (95% CI 4.5 to 31.5)

Thorax 2008;63:775–777

Minimum clinically important improvement for the incremental shuttle walking test

S J Singh,[1,2] P W Jones,[3] R Evans,[1] M D L Morgan[1]

- Minimum clinically important improvement for the ISWT is 47.5 m.
- Patients were able to distinguish an additional benefit at 78.7 m

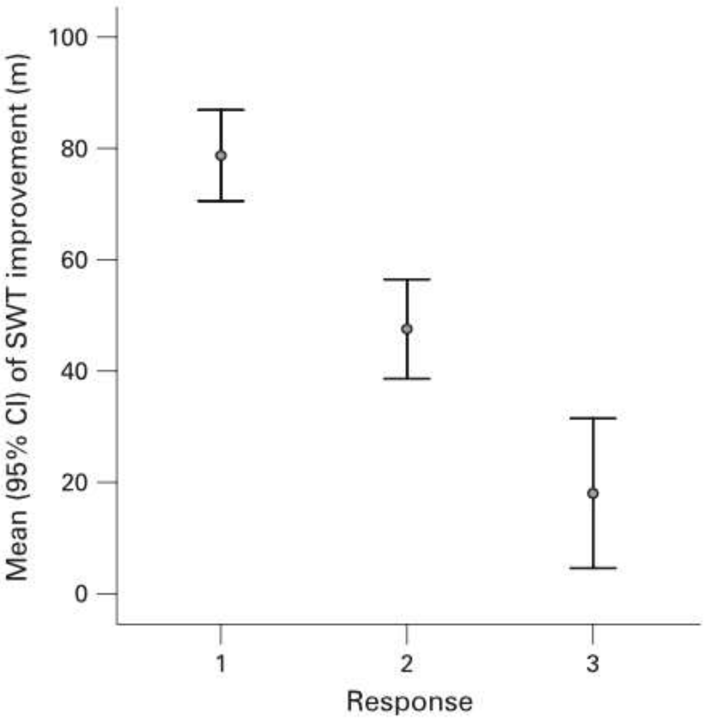


Figure 2 Mean difference (in metres) and 95% confidence intervals in patients whose exercise tolerance was perceived to be "better", slightly better" and "about the same" (responses 1, 2 and 3, respectively).

Thorax 2008;63:775–777

Endurance shuttle walk test

- Procedure is similar to ISWT
- Warm- up period of 1.5 min
- Standardised instructions for the participant played from the audio recording, advising the individual that at the next bleep the speed of walking will increase
- Speed may be taken from a pre-defined percentage of peak performance on the ISWT (e.g. 70–85% estimated VO2peak)
- A triple bleep indicates that the test has started

European Respiratory Journal. 2014 Dec 1;44(6):1428-46

The endurance shuttle walking test: a responsive measure in pulmonary rehabilitation for COPD patients

T Eaton, P Young, K Nicol and J Kolbe
Green Lane Respiratory Services, Auckland City Hospital, Auckland, New Zealand

	Baseline n = 20	*8 weeks n* = 17	*Mean (SD)*	*P-value*	*Standardized mean change (SD)*
Field exercise tests					
ESWT					
Distance, m	313 (193)	633 (526)	302 (387)	0.005	0.54 (0.69)
Time, min	5.1 (2.8)	9.6 (7.0)	4.5 (5.4)	0.004	0.59 (0.71)
Post Borg	4.7 (1.9)	3.9 (2.0)	−0.9 (2.5)	0.168	−0.32 (0.91)
6MWT					
Distance, m	351 (104)	420 (102)	47 (79)	0.038	0.32 (0.54)
Post Borg	4.8 (2.6)	3.9 (2.2)	−0.9 (2.3)	0.145	−0.28 (0.70)

Chron Respir Dis. 2006;3(1):3-9

Significance of changes in endurance shuttle walking performance

Véronique Pepin,[1,2] Louis Laviolette,[3,4] Cynthia Brouillard,[4] Louise Sewell,[5] Sally J Singh,[5] Sue M Revill,[6] Yves Lacasse,[4] François Maltais[4]

Table 2 Improvements in ESWT time according to perception of change

Perception of change	Improvement (s)			
	Rehabilitation		Bronchodilatation	
	N	Δ time (s)	N	Δ time (s)
−3.0	0	–	1	−335.00
−2.0	0	–	6	−194.50±115.78
−1.0	2	144.0±9.9	12	−68.25±47.18
0.0	15	24.9±294.0	29	−2.48±101.20
1.0	21	265.7±308.2	51	22.71±133.65
2.0	46	315.1±356.9	31	103.42±143.37
3.0	48	484.3±374.5	13	90.62±120.00

Values are mean±SD.
ESWT, endurance shuttle walk test.

Patients rated their performance on a 7-point Likert scale. The scale ranged from 3 to +3 and included the following ratings: 3 (large deterioration), 2 (moderate deterioration), 1 (slight deterioration), 0 (no change), 1 (slight improvement), 2 (moderate improvement) and 3 (large improvement)

Thorax 2011;66:115e120

Significance of changes in endurance shuttle walking performance

Véronique Pepin,[1,2] Louis Laviolette,[3,4] Cynthia Brouillard,[4] Louise Sewell,[5] Sally J Singh,[5] Sue M Revill,[6] Yves Lacasse,[4] François Maltais[4]

Table 3 Improvements in ESWT distance according to perception of change

Perception of change	Improvement (s) Rehabilitation N	Rehabilitation Δ distance (m)	Bronchodilatation N	Bronchodilatation Δ distance (m)
−3.0	0	–	1	−460.0
−2.0	0	–	6	−377.5±278.0
−1.0	2	96.7±41.3	12	−87.5±52.1
0.0	15	14.7±250.2	29	−7.9±137.7
1.0	21	259.3±455.5	51	37.6±197.3
2.0	46	276.3±312.3	31	140.6±192.9
3.0	48	492.7±445.3	13	179.2±278.1

Values are mean±SD.
ESWT, endurance shuttle walk test.

Patients rated their performance on a 7-point Likert scale. The scale ranged from 3 to +3 and included the following ratings: 3 (large deterioration), 2 (moderate deterioration), 1 (slight deterioration), 0 (no change), 1 (slight improvement), 2 (moderate improvement) and 3 (large improvement)

Thorax 2011;66:115e120

6 minute walk test

- Performed along a flat, straight course with a hard surface
- Walking course be 30 m or more in length
- Ends of the course should be marked such that they are easily visible to patients
- Patient should be encouraged every 60 s using the standard phrases
- If the patient stops walking during the test, the timer must not be stopped. The patient should be allowed to rest while sitting or standing, as they prefer
- While the patient is stopped, standardised encouragement should be provided every 30 s
- Time that the patient stopped and the time that walking is recommenced should be recorded

Eur Respir J 2014; 44: 1447–1478

6 minute walk test

TABLE 6 Standardised encouragement for the 6-min walk test

1 min	You are doing well. You have 5 minutes to go.
2 min	Keep up the good work. You have 4 minutes to go.
3 min	You are doing well. You are halfway.
4 min	Keep up the good work. You have only 2 minutes left.
5 min	You are doing well. You have only 1 minute to go.
6 min	Please stop where you are.
If the patient stops during the test, every 30 s once S_{pO_2} is ≥85%	Please resume walking whenever you feel able.

Eur Respir J 2014; 44: 1447–1478

6 minute walk test

- Oxyhemoglobin saturation
- Heart rate
- Dyspnea
- Subjective fatigue
- 6 min walk work (6 min walk distance * body weight)

Eur Respir J 2014; 44: 1447–1478

6 minute walk test

- Reliable
- Safe
- Minimally important clinical difference of 30 m for adult patients with chronic respiratory disease

Eur Respir J 2014; 44: 1447–1478

6min walk test – recording sheet

6 Minute walk Test
Result Record

Date: …………….

Patient Name……………………………… Age/ Sex………………
CR No………………………………..…CC No………………..
Diagnosis: ……………………………...……………………………

Parameter	**SpO_2 (%)**	**Pulse Rate(bpm)**	**BP (mm of Hg)**
Base Line			
Post 6MWD			

Parameter	Baseline	During Test	Post Test
Dyspnoea			
Fatigue			

Minimum SpO_2 during test =

Laps	**Time**	**SpO_2(%)**	**PR (bpm)**
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Total Distance:

Limiting Factors

SOB ☐ Low SpO_2 ☐ Leg fatigue ☐

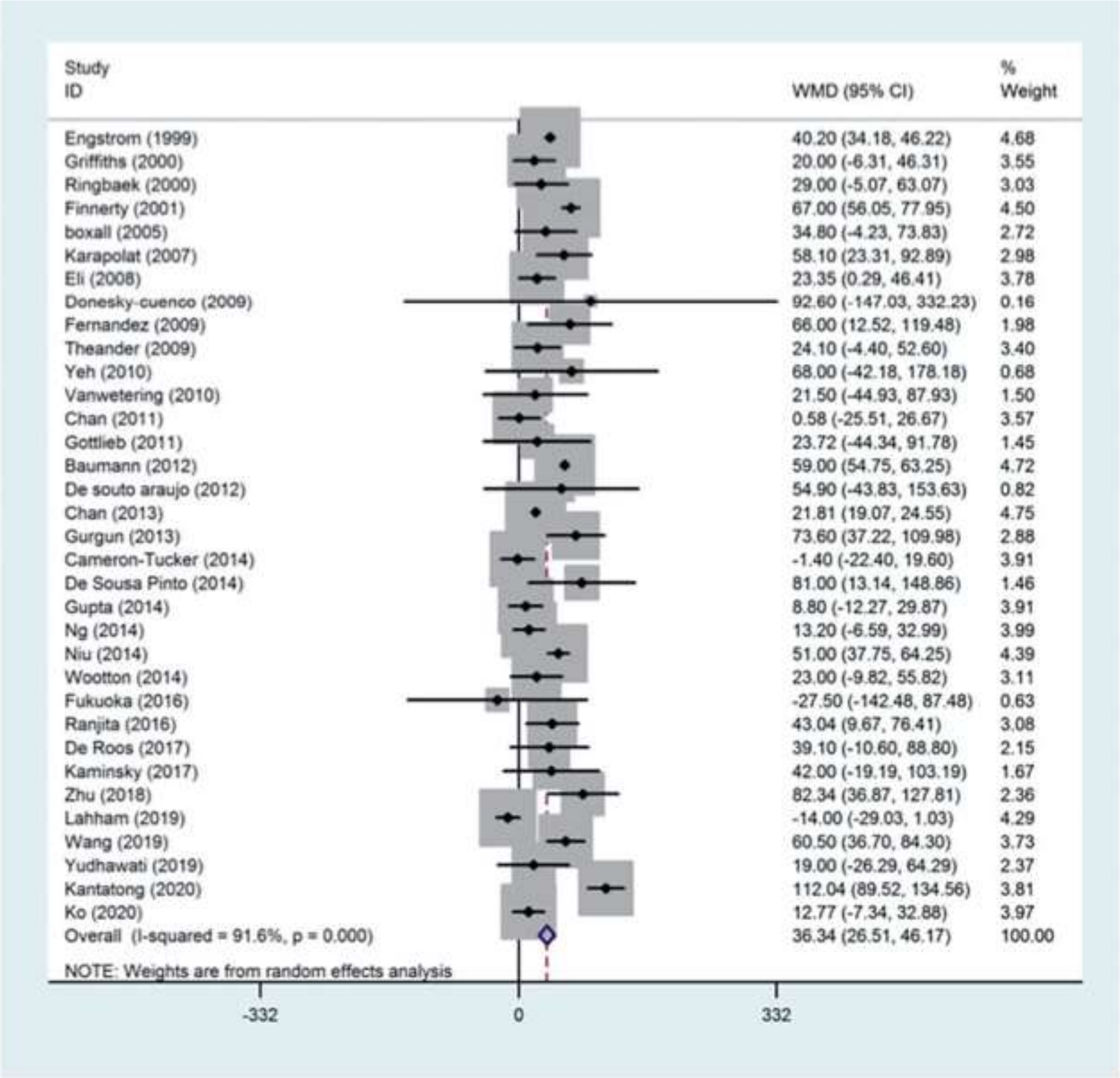
Others ☐

ORIGINAL ARTICLE

OPEN ACCESS Check for updates

Effect of pulmonary rehabilitation in patients with chronic obstructive pulmonary disease: a systematic review and meta-analysis of randomized controlled trials

Hong Zhang, Dandan Hu, Yikai Xu, Lixia Wu and Liming Lou



- Changes in the exercise capacity from baseline were measured using 6MWT in 34 studies.
- 6MWT distance was significantly improved (weighted mean difference (WMD), 36.34; 95% confidence interval (CI): 26.51–46.17; p < .001; in the pulmonary rehabilitation group compared to the control group

Annals of medicine. 2022 Dec 31;54(1):262-73

Cochrane Library

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Pulmonary rehabilitation for chronic obstructive pulmonary disease (Review)

McCarthy B, Casey D, Devane D, Murphy K, Murphy E, Lacasse Y

Change in functional exercise capacity (6MWT)) Distance metres Follow-up: median 12 weeks	Median change = 3.4 metres	Mean functional exercise capacity (6MWT)) in the intervention groups was **43.93 metres higher** (32.64 to 55.21 higher)

Cochrane Database Syst Rev. 2015 Feb 23;2015(2)

Small changes in six-minute walk distance are important in diffuse parenchymal lung disease

Anne E. Holland [a,b,*], Catherine J. Hill [c,d], Matthew Conron [e], Prue Munro [b], Christine F. McDonald [d,f]

- N=48 subjects
- 24 Idiopathic pulmonary fibrosis
- Underwent exercise programme for 8 weeks
- 6 min walk test before and after 8 weeks
- Minimally important difference 30.5 m (area under the curve 0.89, 95% confidence interval 0.81-0.98)

Respir Med. 2009 Oct;103(10):1430-5

Reference equations for 6 min walk tests

First author [ref.]	Sex	Reference equation	r^2
Casanova [173]	Males	$6MWD=361-(age \times 4)+(height \times 2)+(3 \times HR_{max}/HR_{max\%pred})-(weight \times 1.5)$	0.09–0.73#
	Females	$6MWD=361-(age \times 4)+(height \times 2)+(3 \times HR_{max}/HR_{max\%pred})-(weight \times 1.5)-30$	0.09–0.73#
Dourado [174]	Both	$6MWD=299.296-(2.728 \times age)-(2.160 \times weight)+(361.731 \times height^{\P})+(56.386 \times sex^{\S})$	0.54
	Both	$6MWD=109.764-(1.794 \times age)-(2.383 \times weight)+(423.110 \times height^{\P})+(2.422 \times grip\ strength)$	0.54
Hill [175]	Both	$6MWD=970.7+(-5.5 \times age)+(56.3 \times sex^{\S})$	
Soares [176]	Both	$6MWD=511+(height^2 \times 0.0066)-(age^2 \times 0.030)-(BMI^2 \times 0.068)$	
Osses [177]	Males	$6MWD=530-(3.31 \times age)+(2.36 \times height)-(1.49 \times weight)$	0.55
	Females	$6MWD=457-(3.46 \times age)+(2.61 \times height)-(1.57 \times weight)$	0.63
Alameri [178]	Both	$6MWD=(2.81 \times height)+(0.79 \times age)-28.5$	0.25
Ben Saad [179]	Both	$6MWD=720.50-(160 \times sex^{f})-(5.14 \times age)-(2.23 \times weight)+(2.72 \times height)$	0.77
Iwama [180]	Both	$6MWD=622.461-(1.846 \times age)+(61.503 \times sex^{\S})$	0.30
Jenkins [181]	Males	$6MWD=867-(5.71 \times age)+(1.03 \times height)$	
	Females	$6MWD=525-(2.86 \times age)+(2.71 \times height)-(6.22 \times BMI)$	
Masmoudi [182]	Both	$6MWD=299.8-(4.43 \times age)+(342.6 \times height^{\P})-(1.46 \times weight)+(62.5 \times sex^{f})$	0.60
Camarri [183]	Both	$6MWD=64.69+(3.12 \times height)+(23.29 \times FEV_1)$	0.43
	Both	$6MWD=216.90+(4.12 \times height)-(1.75 \times age)-(1.15 \times weight)-(34.04 \times sex^{f})$	0.36
Chetta [184]	Both	$6MWD=518.853+(1.25 \times height)-(2.816 \times age)-(39.07 \times sex^{f})$	0.42
Poh [185]	Both	$6MWD=(5.50 \times HR_{max}/HR_{max\%pred})+(6.94 \times height)-(4.49 \times age)-(3.51 \times weight)-473.27$	0.78
Gibbons [186]	Both	$6MWD=868.8-(age \times 2.99)-(sex^{f} \times 74.7)$	0.41
Enright [187]	Males	$6MWD=510+(2.2 \times height)-(0.93 \times weight)-(5.3 \times age)$	0.20
	Females	$6MWD=493+(2.2 \times height)-(0.93 \times weight)-(5.3 \times age)$	0.20
Troosters [188]	Both	$6MWD=218+(5.14 \times height)-(5.32 \times age)-(1.80 \times weight)+(51.31 \times sex^{\S})$	0.66
Enright [189]	Males	$6MWD=(7.57 \times height)-(5.02 \times age)-(1.76 \times weight)-309$	0.42
	Females	$6MWD=(2.11 \times height)-(2.29 \times weight)-(5.78 \times age)+667$	0.38
	Males	$6MWD=1.140-(5.61 \times BMI)-(6.94 \times age)$	
	Females	$6MWD=1.017-(6.24 \times BMI)-(5.83 \times age)$	

Eur Respir J 2014; 44: 1447–1478

The Harvard Step test

- Cardiopulmonary exercise test
- Its advantages are in measuring the fitness level and recovery rate capability, following an energetic exercise. During recovery, shorter time for HR to return to resting values, suggests better fitness level
- It is also a good measurement of fitness and a person’s ability to recover, after an all-out exercise
- The Harvard-Step-Test characteristic is an endurance fitness test
- The test calculates the ability to exercise nonstop for lengthy intervals of time without exhausting

The Harvard Step test

- The Harvard-Step-Test is conducted as follows:
- The individual taking the test steps up and down 150 times on a platform in a cycle of one-step per 2 s for 5 min.
- The platform is at a height of about 50 cm or 20 inches.
- Subjects must hold rate of 30 steps per minute up for 5 min or until exhaustion.
- To ensure the right speed, a metronome is used

The Harvard Step test

- Exhaustion is the point at which the subject cannot maintain the stepping rate for 15 s
- With the test completion, the subject immediately sits down and measures its heartbeats postexercise, between 1 to 1.5 min (pulse 1), 2 to 2.5 min (pulse 2), and 3 to 3.5 min (pulse 3)
- Results are written down and plotted as a simple fitness index equation: $(te \cdot 100)/(HR \cdot 2)$
- te = time until exhaustion in seconds; HR = total heartbeats counted

The Harvard Step test

Rating	Fitness level
Excellent	96 and above
Good	83–95
Average	68–82
Low average	54–67
Poor	53 and less

The Harvard Step test

- Example
- Following 5 min (300 s), HRs measured were as follows: Pulse 1 = 50 beats, Pulse 2 = 55 beats, Pulse 3 = 60 beats. Total heart beats = 50 + 55 + 60 = 165
- Fitness index = (300 · 100) / (165 · 2) = 91

CLINICAL LUNG AND HEART/LUNG TRANSPLANTATION

The 15-Step Oximetry Test: a Reliable Tool to Identify Candidates for Lung Transplantation Among Patients With Idiopathic Pulmonary Fibrosis

David Shitrit, MD,[a,b] Victorya Rusanov, MD,[a,b] Nir Peled, MD,[a,b] Anat Amital, MD,[a,b] Leonardo Fuks, MD,[a,b] and Mordechai R. Kramer, MD[a,b]

- N = 51 patients with progressive idiopathic pulmonary fibrosis
- Findings on the 15-step climbing test, pulmonary function tests, cardiopulmonary exercise test and 6-minute walk distance test were assessed at baseline
- Participants were prospectively followed for 2 years to determine the relationship between the test parameters and survival

J Heart Lung Transplant. 2009 Apr;28(4):328-33

Table 2. Main Results of Cardiopulmonary Exercise Test, 6-Minute Walk Distance Test and 15-Step Climbing Test in 51 Patients With Idiopathic Pulmonary Fibrosis

Parameters	Value
Resting pulmonary function	
FEV_1 (% predicted)	61 ± 21
FVC (% predicted)	62 ± 2
TLC (% predicted)	65 ± 15
RV (% predicted)	89 ± 25
DLco (% predicted)	36 ± 14
Cardiopulmonary exercise test	
Vo_2max (ml/kg/min)	11 ± 3
Breathing reserve (liters/min)	25 ± 19
Saturation at the end of exercise (%)	88 ± 6
6-minute walk distance test	
Saturation at rest (%)	94 ± 3
Saturation after exercise (%)	86 ± 8
Saturation difference (%)	8 ± 7
Distance (m)	397 ± 98
15-step climbing test	
Saturation baseline (%)	95 ± 3
Saturation lowest (%)	86 ± 7
Saturation difference (%)	9 ± 5
Exercise time (sec)	52 ± 12
Desaturation time (sec)	74 ± 21
Recovery time (sec)	78 ± 44
Desaturation area (sec%)	1,314 ± 1,078

Table 3. Comparison of Clinical Data of Patients Who Survived and Patients Who Did Not Survive or Underwent Lung Transplantation ($n = 51$)

Characteristic	Survived ($n = 29$)	Did not survive or lung transplanted ($n = 22$)	p-value
Age (years)	61 ± 13	55 ± 7	0.075
M:F	22:7	12:10	0.520
FVC (% predicted)	64 ± 21	54 ± 15	0.067
FEV_1 (% predicted)	66 ± 23	54 ± 14	0.04
TLC (% predicted)	68 ± 15	60 ± 12	0.053
RV (% predicted)	90 ± 25	88 ± 24	0.90
DLco (% predicted)	42 ± 14	27 ± 7	0.0001
Saturation at rest (%)	95 ± 2	92 ± 2	0.0001
Saturation after 6MWD (%)	89 ± 6	82 ± 8	0.005
6MWD (m)	417 ± 111	369 ± 69	0.085
Vo_2max (kg/ml/min)	12 ± 3.7	9.5 ± 1.9	0.005
Lowest saturation for 15-step test (%)	88 ± 6	82 ± 6	0.0007
Saturation differences 15-step test (%)	7.2 ± 4	10 ± 4	0.0001
Exercise time, 15-step test (sec)	51 ± 12	52±11	0.92
Desaturation time (sec)	70 ± 23	78 ± 18	0.164
Recovery time (sec)	62 ± 32	97 ± 48	0.004
Desaturation area (sec%)	868 ± 799	1,901 ± 1,131	0.0001

J Heart Lung Transplant. 2009 Apr;28(4):328-33

The Cooper 12 min Walk/Run Test

- The Cooper 12-min run test requires the person being tested to run or walk as far as possible in a 12 min time
- The purpose of the 12-min run/walk test is to cover a maximum distance during the 12 min period
- The test is usually executed in a stadium, on the running track, where the distance of each lap is known. It is an easy test to perform on large groups

The Cooper 12 min Walk/Run Test

- **Equipment Needed**
- A stopwatch is needed to ensure that the individual runs for the correct amount of time.
- Safety First. This field test is a stress fitness test and therefore it is recommended to have a medical backup while performing the test
- Location. This test takes place on a stadium track with clearly marked distance. In addition, it is possible to perform the test on a treadmill, with an inclination of one degree. Speed can be changed as the individual feels to simulate outdoor running

The Cooper 12 min Walk/Run Test

- Before starting the test, a short warm-up for 10–15 min is advised
- Following the warm-up, the individual runs or walks as far as he/she can within 12 min
- The total number of miles or kilometers covered in 12 min should be recorded
- Results can be transferred to VO2max as follows

In meters: VO2 max =(d12-504.9)/44.73

where d12 = distance covered (in meters) in 12 min

Alternatively, In miles : VO2max = (35.97 × miles)-11.29

The Cooper 12 min Walk/Run Test

Table 3.2 Comparing individual results for group's norms by age and gender

Age males	Excellent	Above average	Average	Below average	Poor
20–29	2800	2400 = 2800	2200–2399	1600–2199	1600
30–39	2700	2300–2700	1900 = 2299	1500–1999	1500
40–49	2500	2100–2500	1700–2099	1400–1699	1400
50 + >	2400	200–2400	1600–1999	1300–1599	1300

Age females	Excellent	Above average	Average	Below average	Poor
20–29	>2700	2200–2700	1800–2199	1500–1799	<1500
30–39	>2500	2000–2500	1700–1999	400–1699	<1400
40–49	>2300	1900–2300	1500–1899	1200–1499	<1200
50 + >	>2200	1700–2200	1400–1699	1100–1399	<1100

Laboratory tests

Incremental Work test

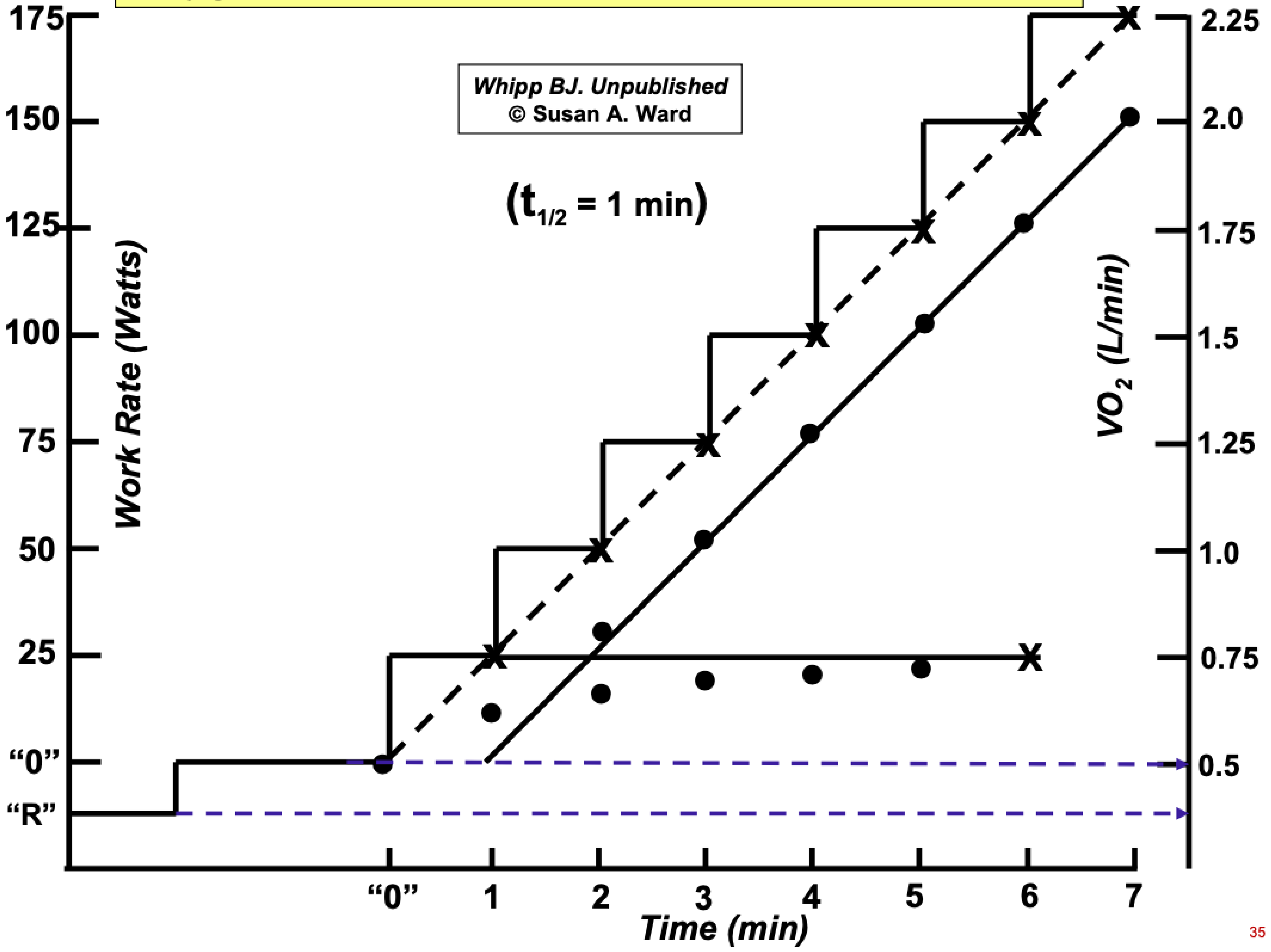
- Evaluation of both submaximal and peak exercise responses
- identification of underlying mechanisms of exercise intolerance

- **Procedure**
- Procedure standardised and is automated (i.e. computer-driven cycle ergometer or treadmill)
- Cycle ergometer > treadmill (less expensive, occupies little space, less prone to movement, requires relatively little patient practice and (unlike the treadmill) the external power output is accurately known)

Incremental work test

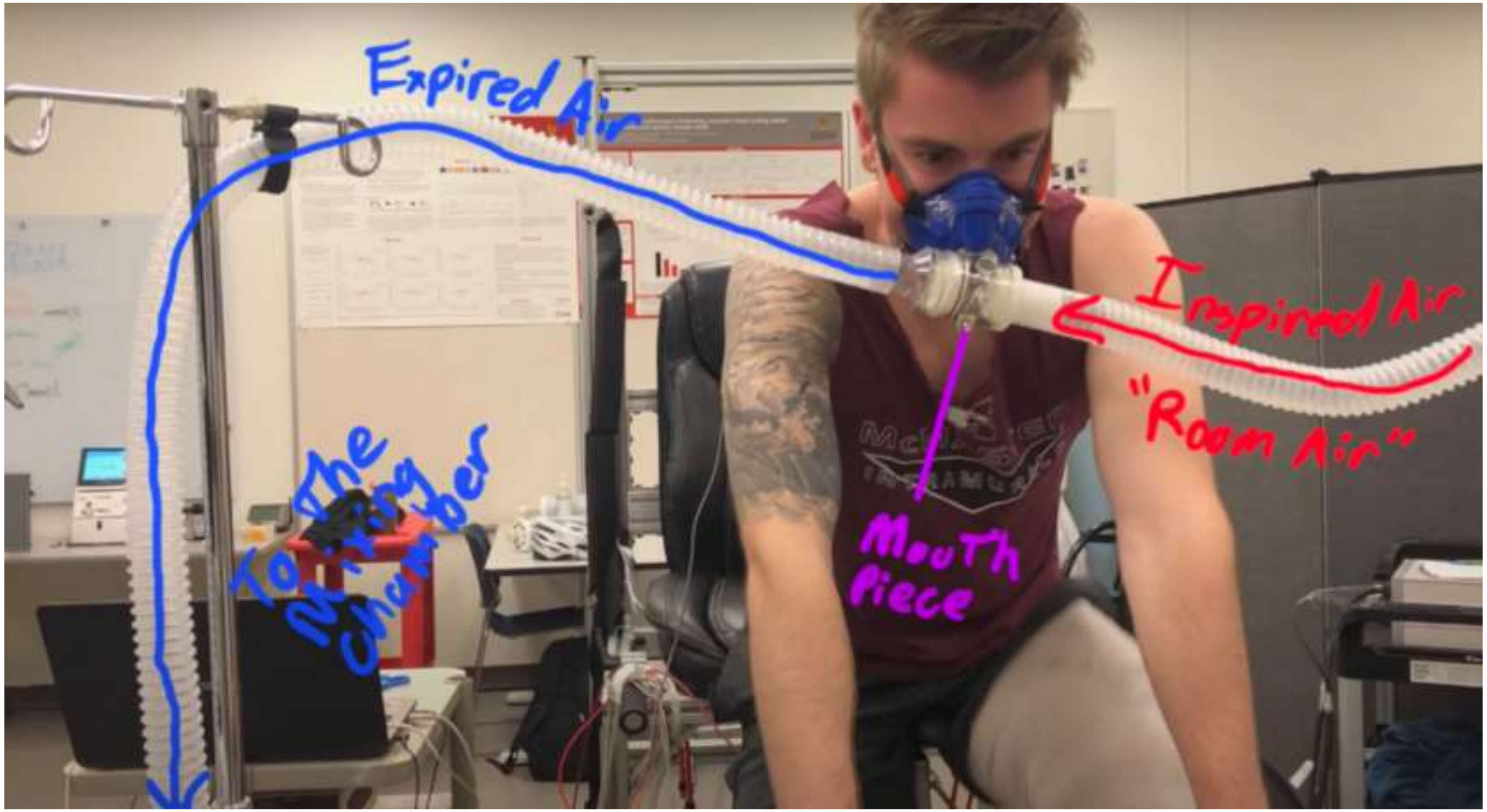
- Consists of baseline measurements lasting at least 2–3 minutes
- Then a warm-up period of 3 minutes unloaded work
- Followed by the incremental part of the exercise test
- Ideally, peak work rate should be reached within 8–12 minutes
- WR is incremented ($\Delta WR/\Delta t$) for an IET such that the tolerable limit (tLIM) is reached within ∼10 min
- $\Delta WR/\Delta t$ of 5–10 $W \cdot min^{-1}$ may be used in more severe patients to ensure a sufficient test duration

Oxygen Uptake Response to Muscular Exercise

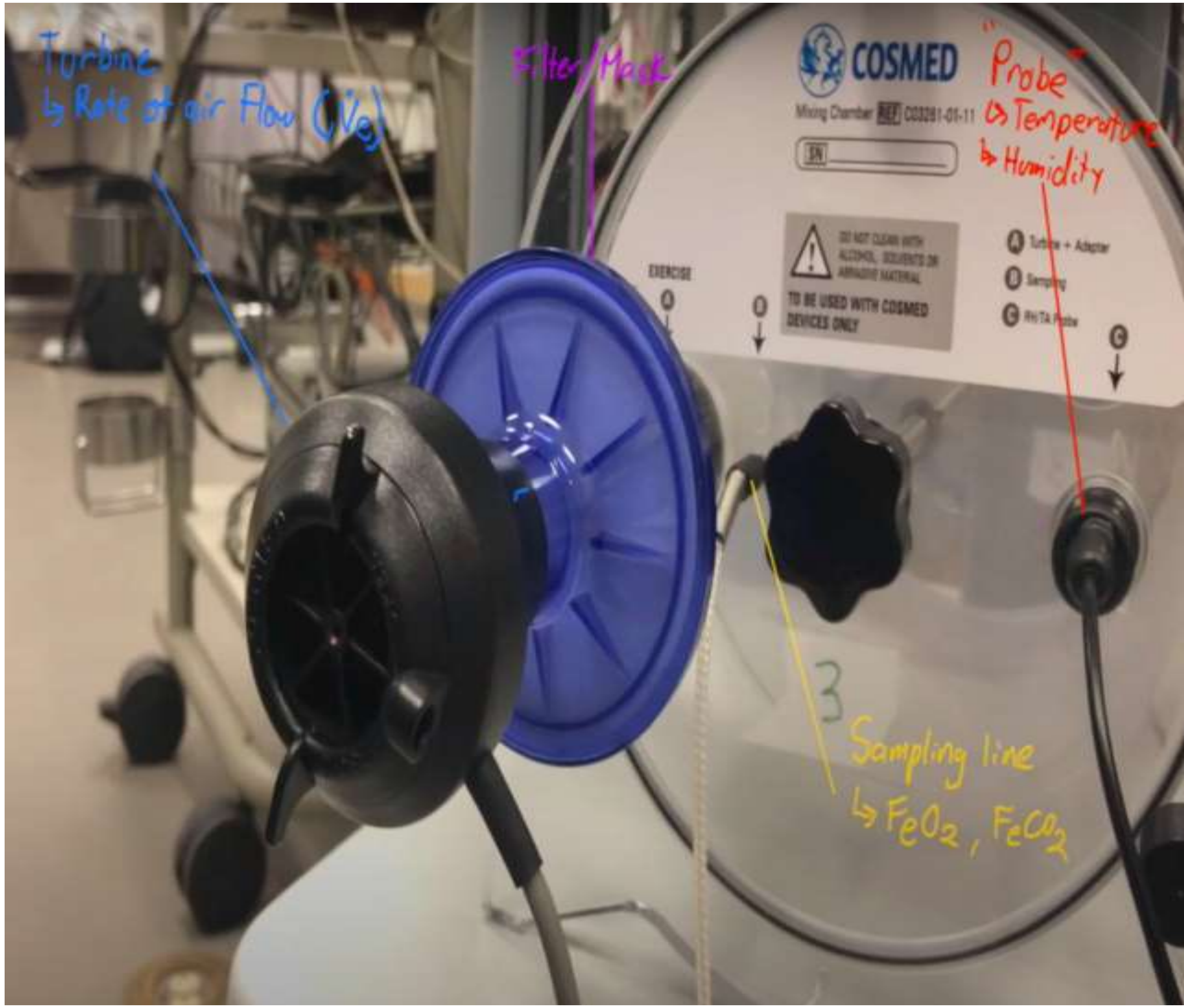


Incremental work test

- **Facilities:**
- Cycle or treadmill, a room, metabolic system, cardiac monitoring and pulse oximeter
- **Safety**
- Adverse events are rare during properly supervised tests


Expired Air
Inspired Air
"Room Air"
Mouth Piece
To the Mixing Chamber


COSMED


Turbine
↳ Rate of air flow ($\dot{V}_E$)
Filter/Mask
COSMED
Mixing Chamber REF C03261-01-11
SN
"Probe"
↳ Temperature
↳ Humidity
DO NOT CLEAN WITH ALCOHOL, SOLVENTS OR ABRASIVE MATERIAL
TO BE USED WITH COSMED DEVICES ONLY
EXERCISE
A Turbine + Adapter
B Sampling
C RH/TA Probe
3
Sampling line
↳ FeO_2, $FeCO_2$


C1
C2
STAT

Maximal oxygen uptake

- VO_2max is the maximum amount of oxygen an individual can consume at peak strenuous exercise
- It is the maximum capacity of an individual's body to transport and use oxygen during incremental exercise, which reflects the physical fitness of the individual.
- VO2max is widely accepted as the single best measure of cardiovascular fitness and maximal aerobic power.
- VO2 is usually expressed relative to bodyweight, measured as milliliters of oxygen used in 1 min per kg of body weight (mLO2 kg−1 min−1)
- VO2 and total energy demands are determined by body size
- Normalize VO2 to body surface area, which can be more accurate when comparing children and gender

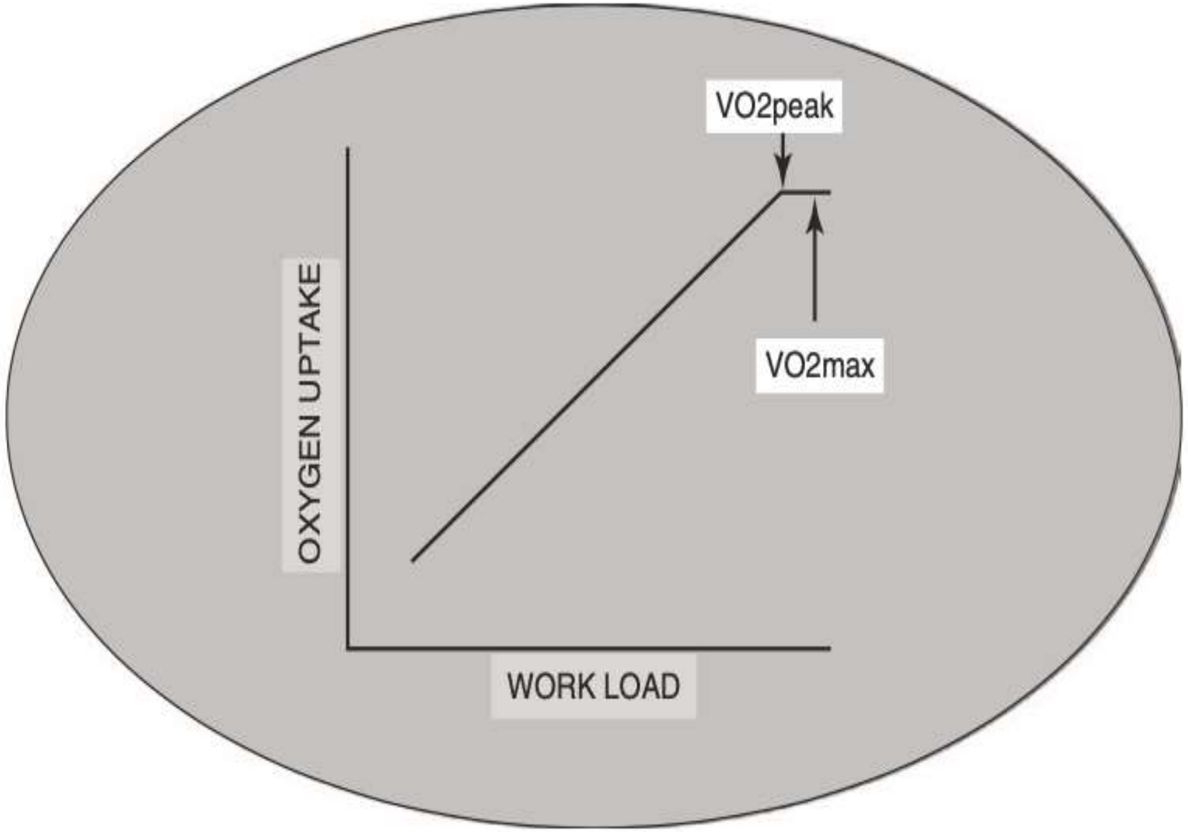


Fig. 3.3 Two different reference points determining VO_{2peak} and VO_{2max}. Determining VO_{2peak} differs from that of VO_{2max}. VO_{2peak} is defined when the subject withdraws voluntarily from the test, while VO_{2max} is defined whenever VO_2 does not increase further with increased intensity

- V'O2peak is an excellent general predictor of survival for most chronic respiratory diseases

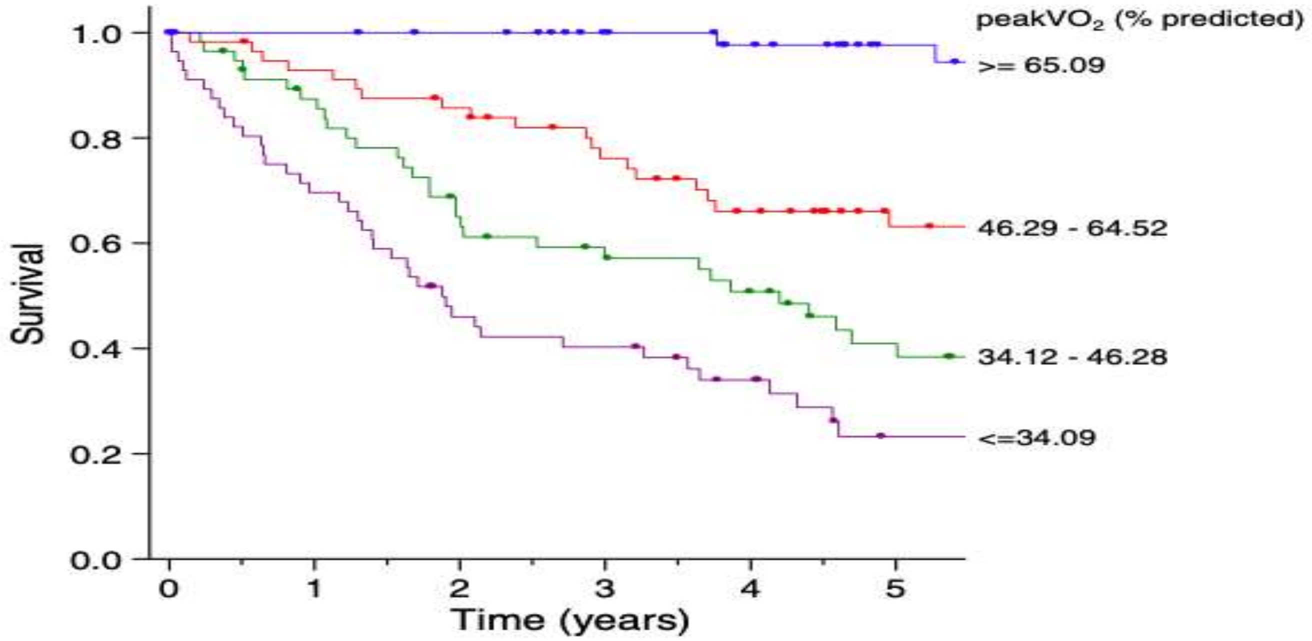
- In studies guage severity
- In Pulmonary artery Hypertension
- COPD
- Interstitial Lung disease

Incremental Exercise test

- 1218 patients enrolled in the National Emphysema Treatment Trial
- COPD - V'O2peak change of $\sim 0.04 \pm 0.01$ $L \cdot min^{-1}$
- 4 ± 1 watt – Minimally important clinically difference

Incremental prognostic value of cardiopulmonary exercise testing and resting haemodynamics in pulmonary arterial hypertension

Roland Wensel [a,b,*], Darrel P. Francis [a], F. Joachim Meyer [c], Christian F. Opitz [d], Leonhard Bruch [e], Michael Halank [f], Jörg Winkler [g], Hans-Jürgen Seyfarth [h], Sven Gläser [i], Friedrich Blumberg [j], Anne Obst [i], Michael Dandel [k], Roland Hetzer [k], Ralf Ewert [i]

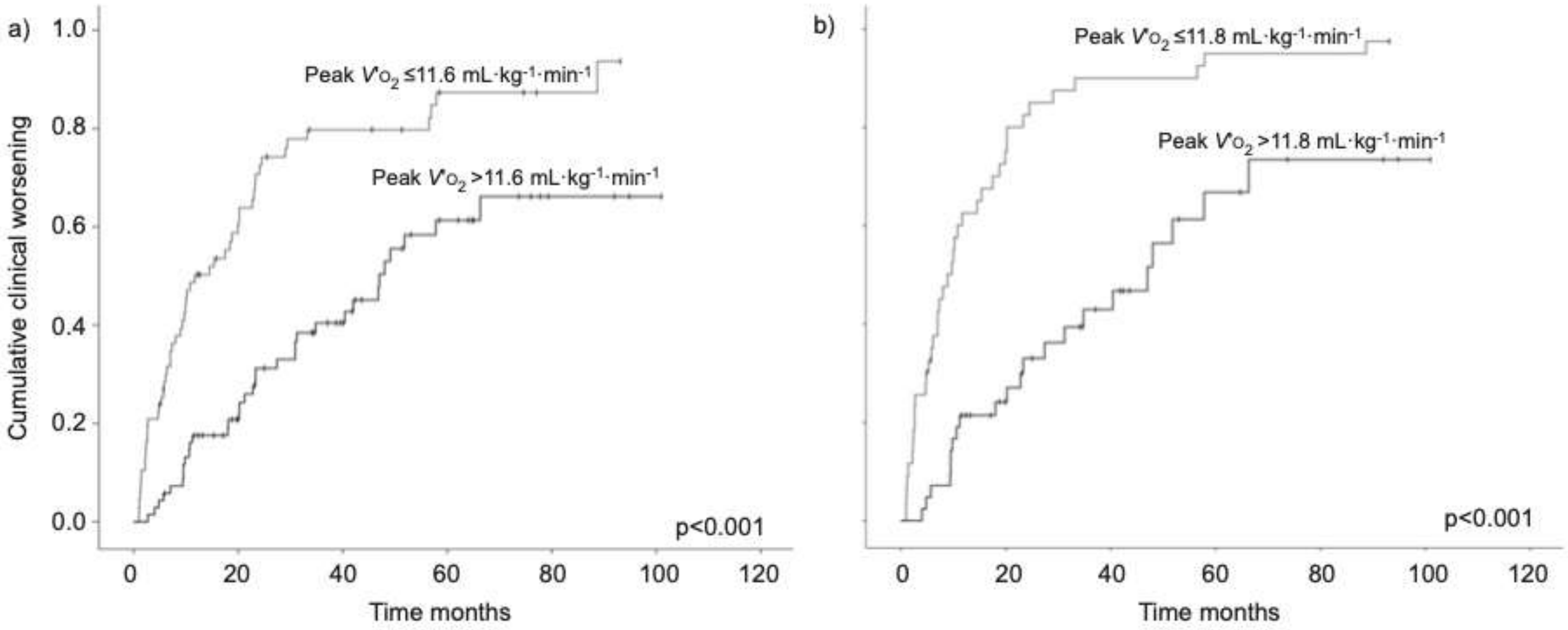


At Risk:	56	--	--	--	42	29
	57	55	45	37	32	20
	57	48	41	33	25	19
	56	36	26	22	20	16
Survival:		1.00†	1.00	1.00	0.98	0.98‡
		0.93*†	0.86	0.76	0.66	0.63‡
		0.88*†	0.65	0.57	0.51	0.41‡
		0.70*	0.46	0.40	0.34	0.23‡

International Journal of Cardiology, 167(4), 1193–1198

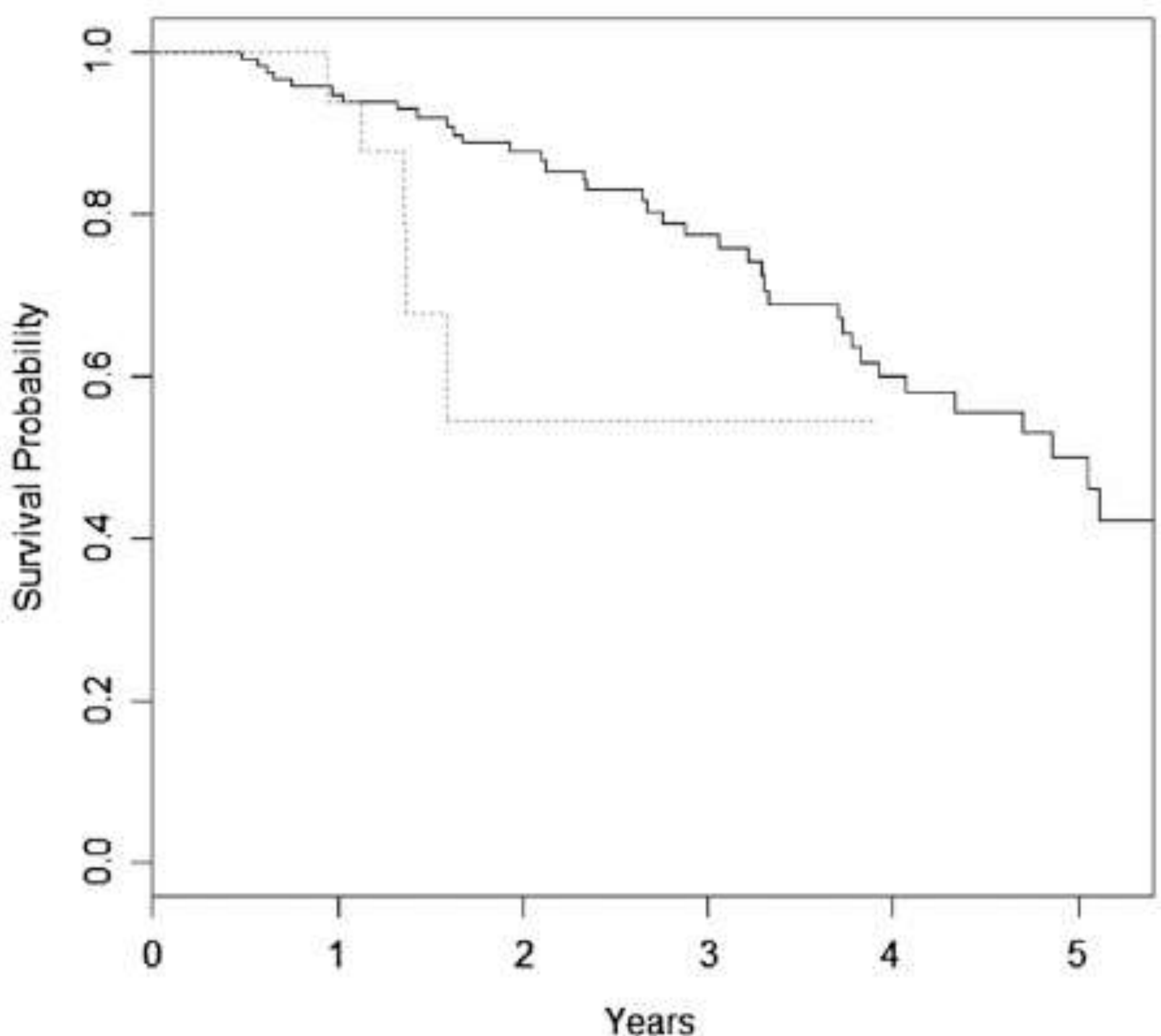
Exercise testing to predict outcome in idiopathic *versus* associated pulmonary arterial hypertension

Gaël Deboeck*, Cristina Scoditti#, Sandrine Huez*, Jean-Luc Vachiéry*, Michel Lamotte*, Linda Sharples¶, Christian Melot+ and Robert Naeije§



The Prognostic Value of Cardiopulmonary Exercise Testing in Idiopathic Pulmonary Fibrosis

Charlene D. Fell[1], Lyrica Xiaohong Liu[2], Caroline Motika[3], Ella A. Kazerooni[4], Barry H. Gross[4], William D. Travis[5], Thomas V. Colby[6], Susan Murray[2], Galen B. Toews[7], Fernando J. Martinez[7], and Kevin R. Flaherty[7]



- Cox proportional hazard survival curves with baseline VO2max greater than 8.3 ml/kg/min (solid line) and less than 8.3 ml/kg/min (dashed line) adjusted for age, sex, smoking status, baseline FVC percent predicted, and baseline DLCO percent predicted

Am J Respir Crit Care Med. 2009 Mar 1;179(5):402-7

Incremental exercise test

- **Peak Work rate**
- WR peak is the highest WR achieved in incremental exercise test at the subject's limit of tolerance
- Coefficients of variation for WR peak in adult respiratory patients range from 3.5% to 13.8%
- Less precise
- Limitation : dependent on the rate of work rate increase increase
- **Post Pulmonary rehabilitation**
- WR peak is at least as responsive as $V'O_2$peak

Cochrane Library

Cochrane Database of Systematic Reviews

Pulmonary rehabilitation for chronic obstructive pulmonary disease (Review)

McCarthy B, Casey D, Devane D, Murphy K, Murphy E, Lacasse Y

Change in maximal exercise capacity (cycle ergometer) Workmax (watt) Follow-up: median 12 weeks	Median change = -0.05 watts	Mean maximal exercise capacity (cycle ergometer) in the intervention groups was **6.77 watts higher** (1.89 to 11.65 higher)	779 (16 studies)

Cochrane Database Syst Rev. 2015 Feb 23;2015(2)

High-intensity constant work-rate exercise tests

- **Procedure:**
- Treadmill or cycle ergometer
- Automated and less operator-dependent
- IET must first be completed (ideally on a separate day or at least allowing a sufficient rest period) for an appropriate work rate for the constant work-rate exercise test to be estimated
- Assign work rate based on a fixed percentage of IET WR peak (CWRET WRs are selected to be 75–80% of IET WRpeak)

Eur Respir J 2016; 47: 429–460

High-intensity constant work-rate exercise tests

- **Facilities:** Cycle or treadmill, a room, metabolic system or spirometer, cardiac monitoring and pulse oximeter
- **Monitoring:**
- Continuous monitoring of SpO2 and ECG
- Concomitant gas exchange measurement increases the value
- **Safety:**
- Safe and cardiopulmonary resuscitation should be available nearby

Eur Respir J 2016; 47: 429–460

High-intensity constant work-rate exercise tests

- **Criteria to determine intolerance:**
- Typical criteria for termination include ⩽10 s sustained below a lower-bound target frequency despite verbal encouragement (typically 60 rpm, but bounds of 50–70 rpm for COPD patients are acceptable
- The point at which the patient is unable to regain the target frequency despite encouragement defines tLIM (time to the limit of tolerance)

Eur Respir J 2016; 47: 429–460

High-intensity constant work-rate exercise tests

- **Termination:**
- It has been recommended that the test should be terminated if SpO2 falls below 80%
- tLIM (time to the limit of tolerance)

- Tolerance time for a CWRET is the duration from the WR imposition to the point of task failure

Eur Respir J 2016; 47: 429–460

High-intensity constant work-rate exercise tests

- **Major variables**
- t LIM iso time
- Isotime Inspiratory capacity and Isotime dyspnea
- **Physiological/ perceptual variables**
- Isotime V’O2,
- Isotime V’E,
- Work Rate, Heart rate , SpO2,
- Leg fatigue, flow–volume and blood analysis

Clinical relevance of constant power exercise duration changes in COPD

L. Puente-Maestu*, F. Villar#, J. de Miguel*, W.W. Stringer¶, P. Sanz*, M.L. Sanz+, J. García de Pedro* and Y. Martínez-Abad*

- 105 patients
- Underwent pulmonary rehabilitation for 8 weeks
- 75% and 85% CWR endurance tests, pre-treatment t LIM was 397 ± 184 s and 315 ±194 s. The average increases in t LIM after intervention are 289 ± 311 s and 138 ± 147 s, or 62 ±63% and 48 ±57%, respectively, for the 75% and 85% CWR tests
- Slightly better: improvement by 34 (29–39)% or 101 (86–116) s in the 75% CWR test and by 31 (25– 34)% or 67 (61–85) s in the 85% CWR test calculated as minimally significant difference

Eur Respir J 2009; 34: 340–345

Clinical relevance of constant power exercise duration changes in COPD

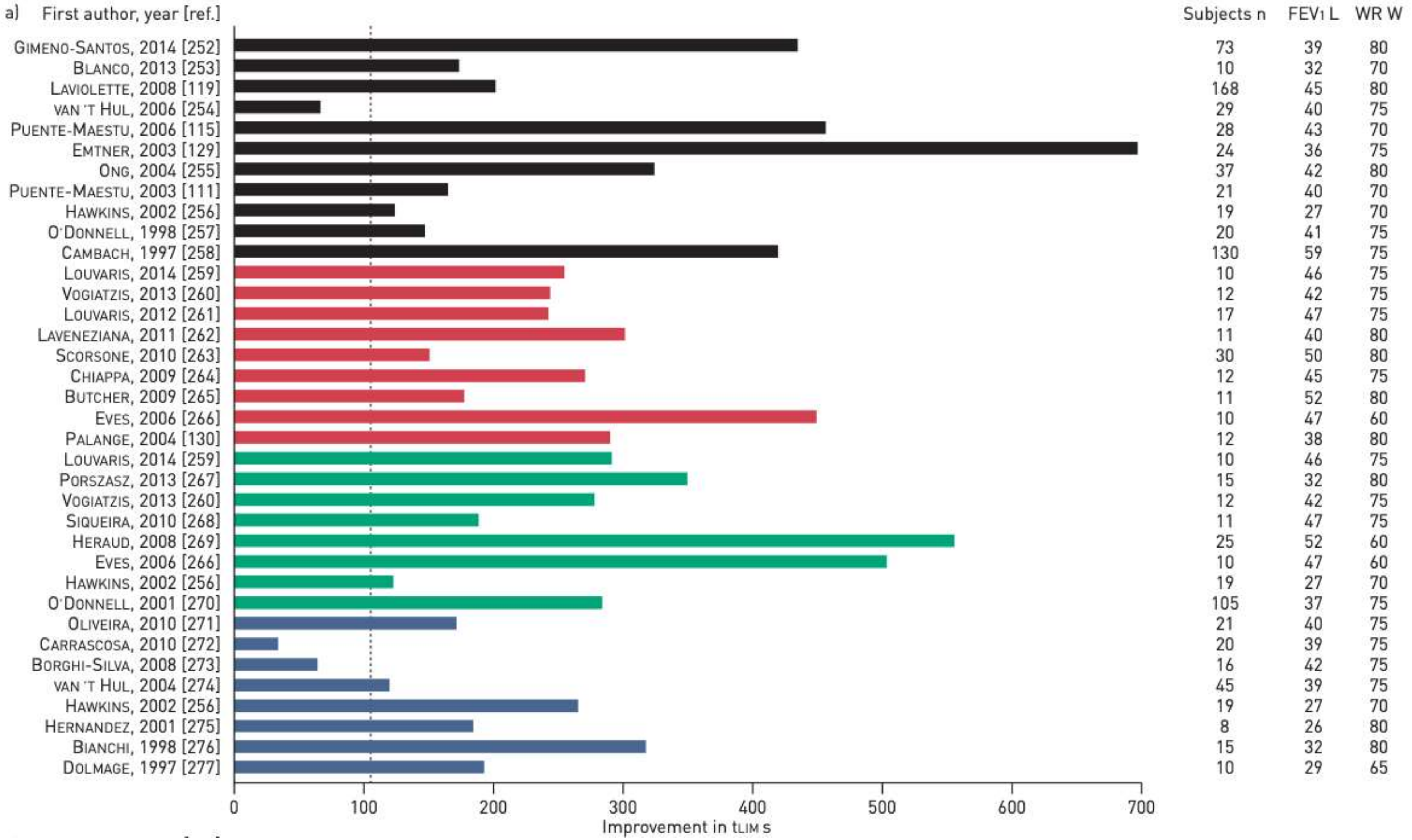
L. Puente-Maestu*, F. Villar#, J. de Miguel*, W.W. Stringer¶, P. Sanz*, M.L. Sanz+, J. García de Pedro* and Y. Martínez-Abad*

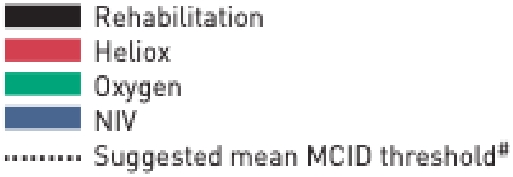
TABLE 4 Change after treatment in the different groups according to their perceived improvement

	"Worse"	"A little bit worse"	"About the same"	"A little bit better"	"Better"
Subjects n	5	7	25	33	35
M/F n	5:0	6:1	21:4	25:8	28:7
Baseline dyspnoea#	16.2±5.5	15.5±4.1	15.4±3.3	15.4±3.3	17.6±1.7*
Baseline $t_{LIM,75}$ s	281±81	293±176	308±180	384±191	456±176
Baseline $t_{LIM,85}$ s	169±45	265±143	248±177	291±177	379±207
$\Delta t_{LIM,75}$ s	-100±54	-29±16	31±32	101±26	521±166
$\Delta t_{LIM,85}$ s	-68±22	-25±16	13±17	67±28	299±120
$\Delta t_{LIM,75}$ %	-35±15	-12±8	12±12	34±16	121±41
$\Delta t_{LIM,85}$ %	-40±17	-15±14	8±14	31±14	92±38
Effect size at 75%¶	-0.8±0.2	-0.2±0.1	0.2±0.1	0.6±0.2	3.2±1.2
Effect size at 85%+	-0.5±0.1	-0.2±0.1	0.2±0.1	0.7±0.3	1.4±0.6
ΔCRQ-D	-5.2±2.7	-1.8±0.7	1.5±1.5	4.2±1.2	10±7

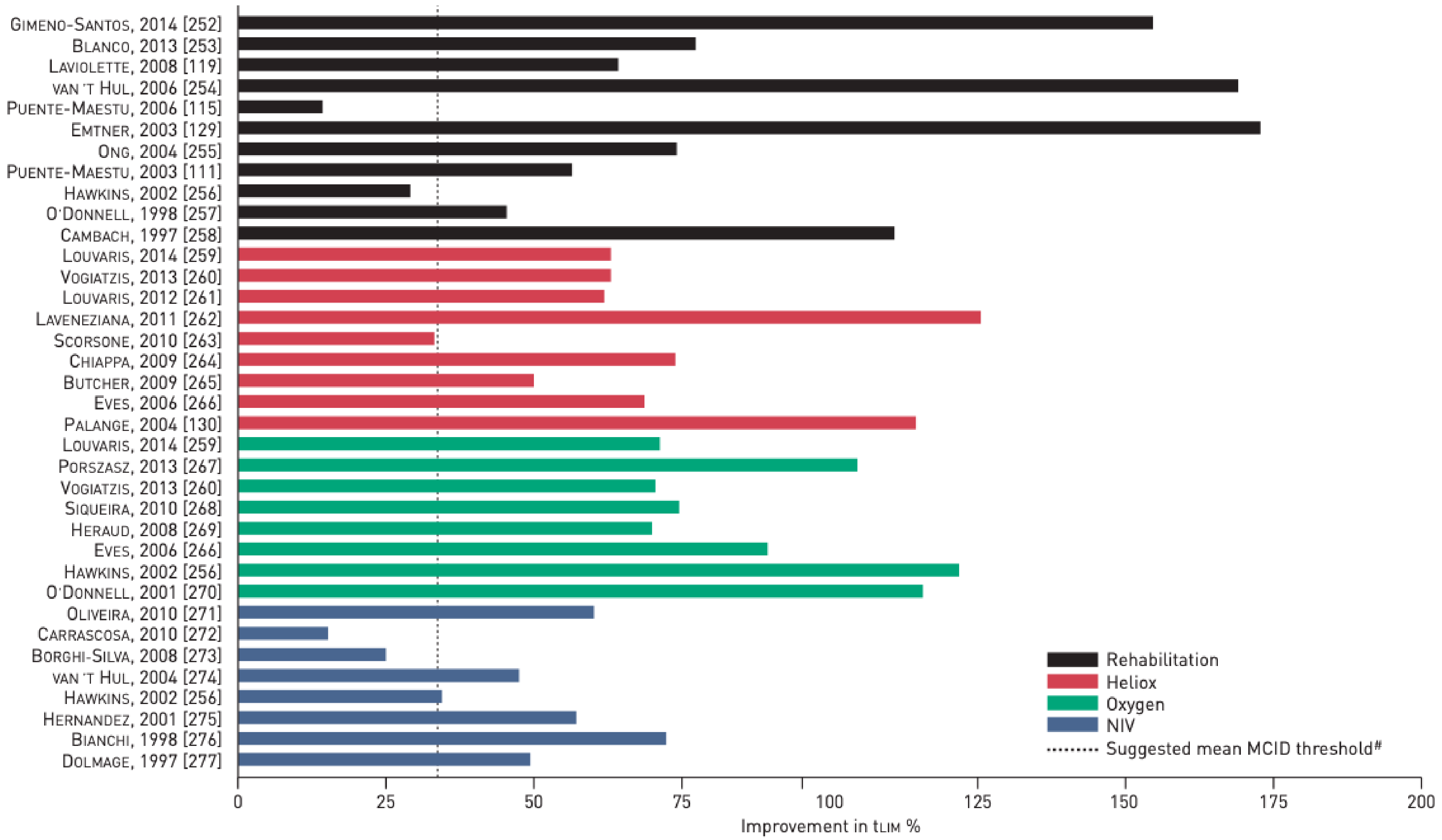
Data are presented as mean±SD, unless otherwise indicated. M: male; F: female; $t_{LIM,75}$ and $t_{LIM,85}$: endurance to constant work-rate test at 75% and 85%, respectively, of the peak work rate; $\Delta t_{LIM,75}$ and $\Delta t_{LIM,85}$: improvement after leg training in the 75% and 85% tests, respectively; ΔCRQ-D: change in the breathlessness score of the chronic respiratory questionnaire initial dyspnoea score. #: CRQ-D score; ¶: $\Delta t_{LIM,75}$ divided by the SD of the baseline 75% test; +: $\Delta t_{LIM,85}$ divided by the SD of the baseline 85% test. *: $p<0.05$.

Eur Respir J 2009; 34: 340–345

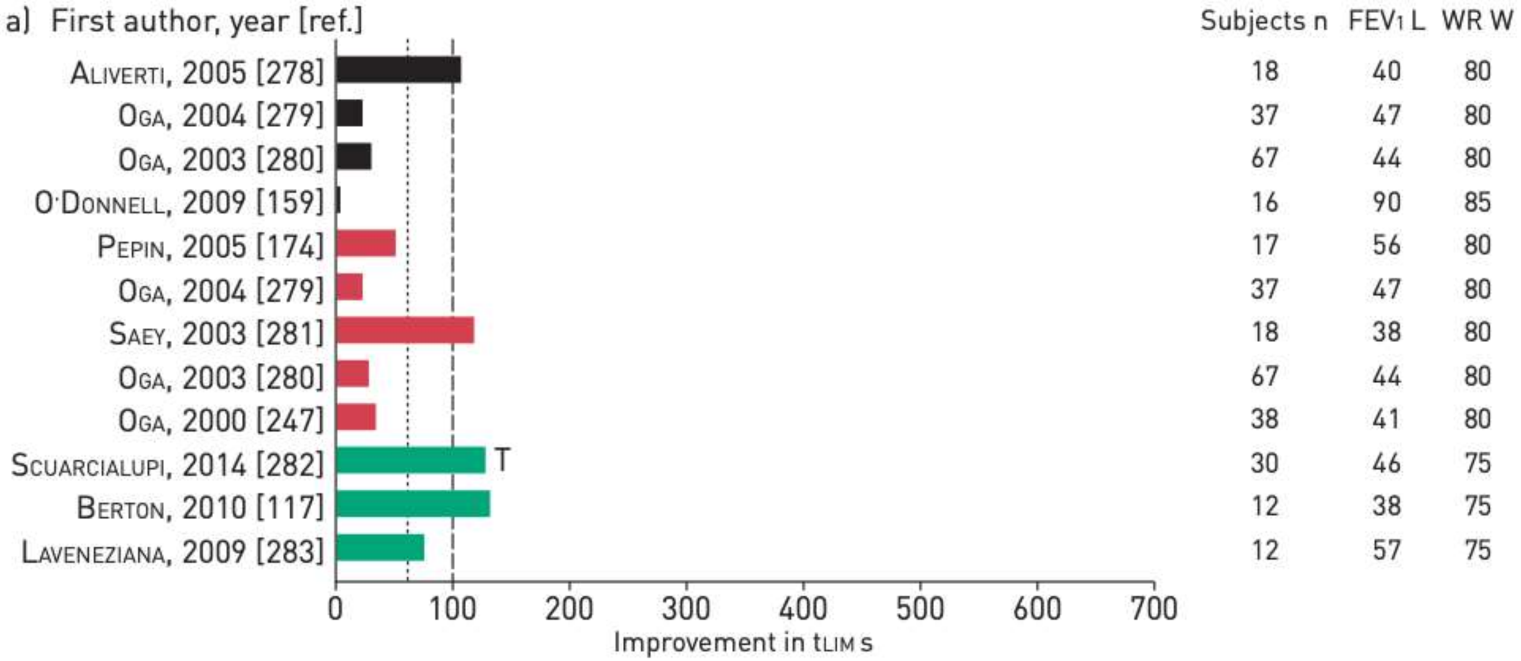




- Mean MCID threshold – 105 s
- Lower limit of 95% CI MCID threshold- 60s



- Mean MCID threshold – 33%
- Lower limit of 95% CI MCID threshold- 22%



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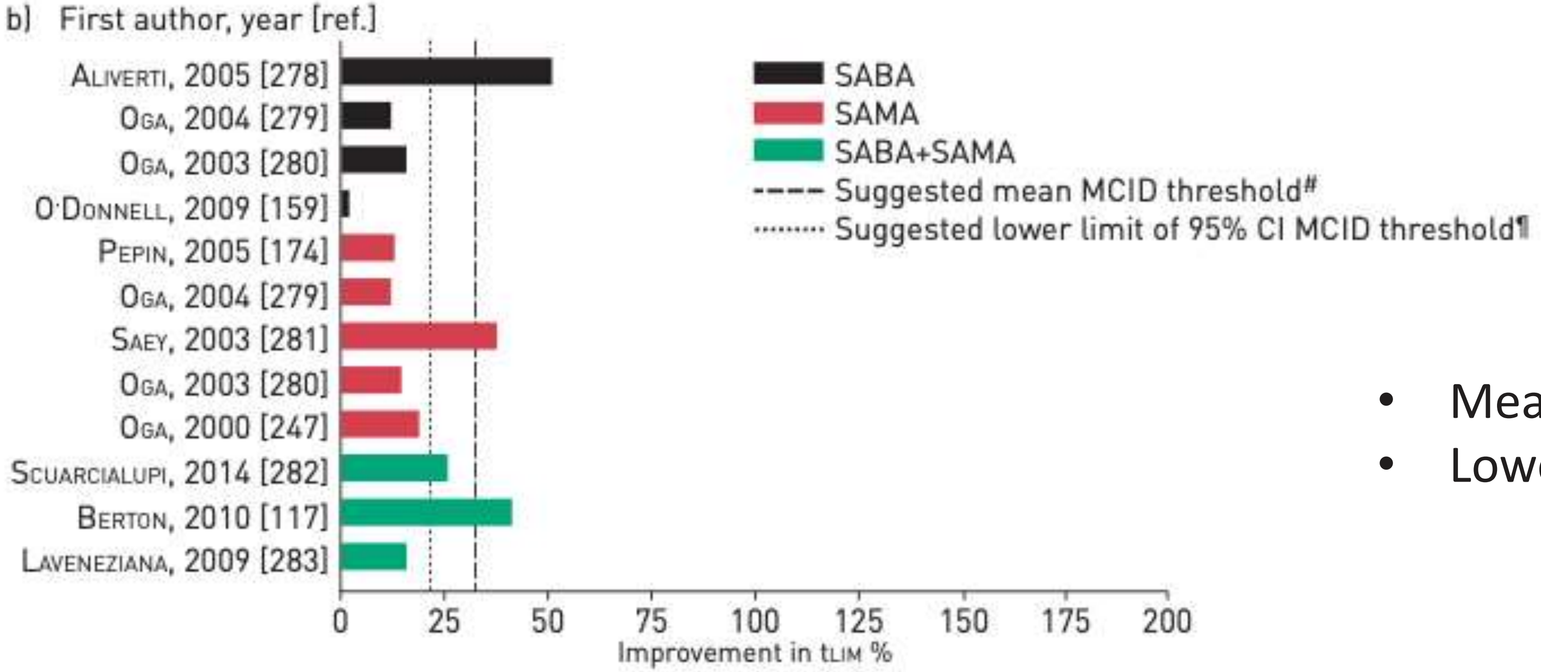

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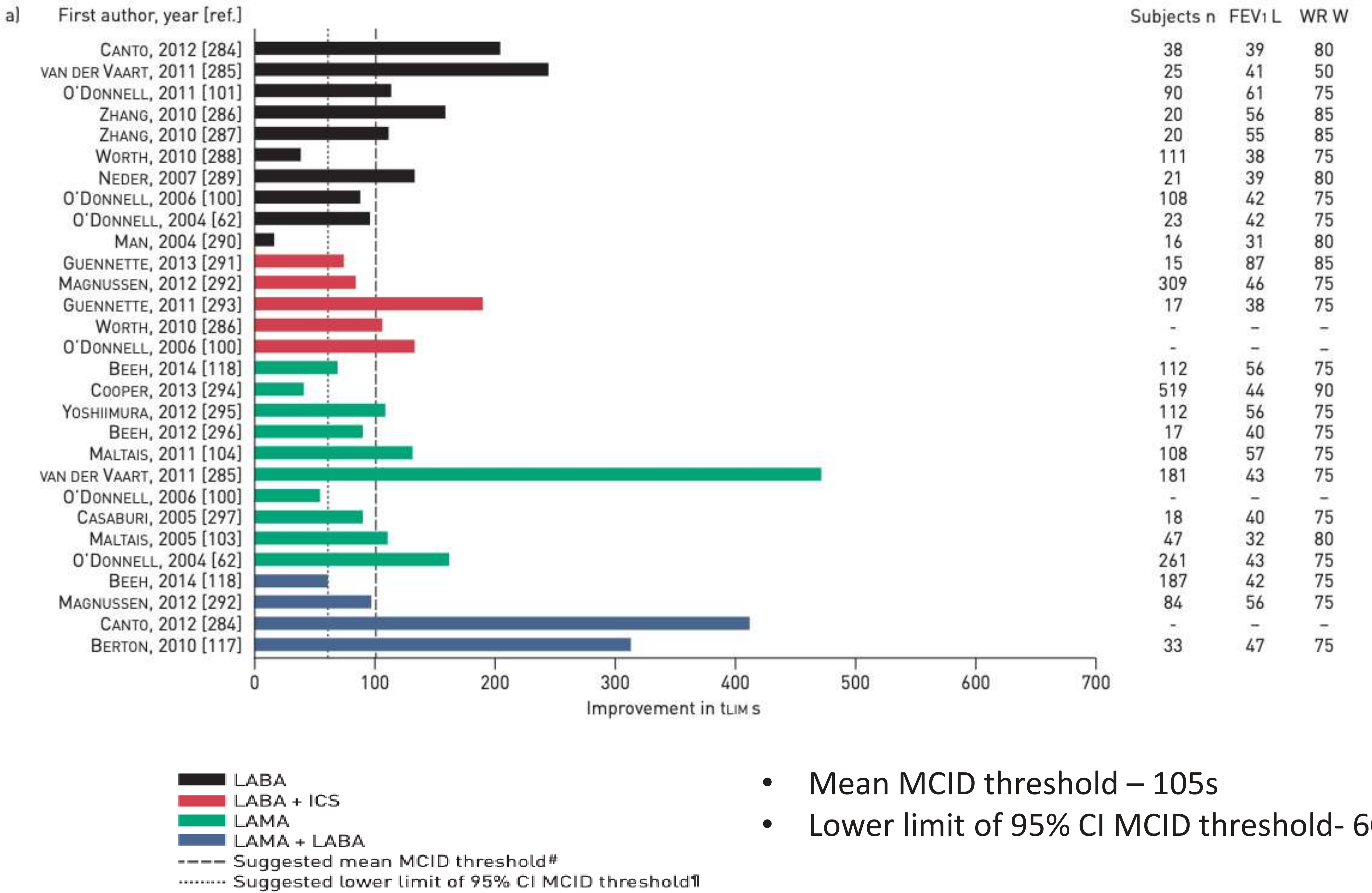

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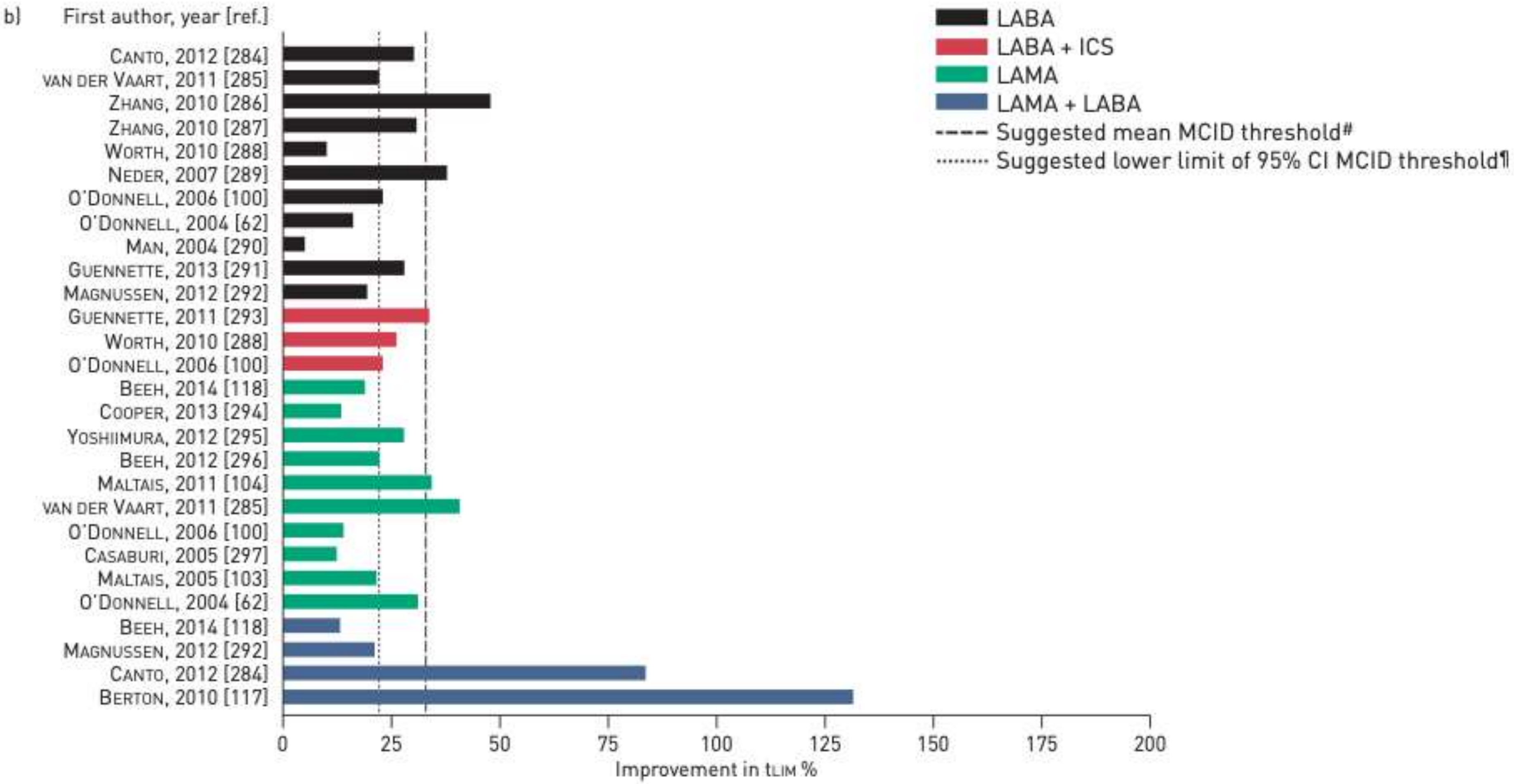


- Mean MCID threshold – 33%
- Lower limit of 95% CI MCID threshold- 22%

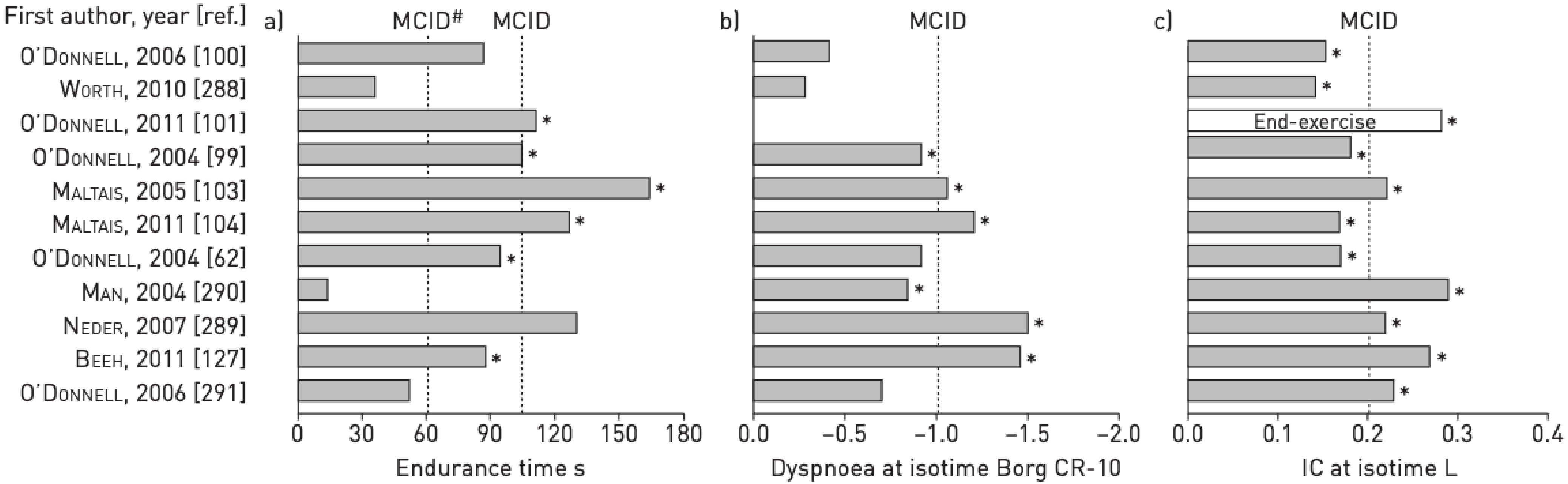
High-intensity constant work-rate exercise tests

- **Isotime responses**
- Measurements of variables made at specific time points
- Responses are effort-independent
- V’O2, V’CO2, V’E, inspiratory capacity, breathing pattern, dyspnoea, leg effort, muscle fatigue, cardiac output, heart rate and arterial lactate concentration
- No specific information has been obtained on the ability of iso time measurements to predict clinical outcomes
- MCID is not established for iso time measurements

High-intensity constant work-rate exercise tests

- **Isotime response – Inspiratory capacity**
- Exercise – dynamic hyperinflation
- Procedure: Subjects are required to take a deep inspiration, after normal expiration, at predetermined intervals during exercise (typically every 2 min)
- Difference between inspiratory capacity at rest and during exercise
- Changes in inspiratory capacity - 0.14 L (or 4.5% predicted) have been consistently associated with significantly increased tLIM in moderate-to-severe COPD patients

High-intensity constant work-rate exercise tests



- Relationships between the changes in a) endurance time (time to the limit of tolerance (tLIM)); b) dyspnoea at iso time; and c) iso time inspiratory capacity (IC) after the administration of bronchodilators. Mean minimal clinically important difference (MCID) thresholds of a) 105 s; b) 1 point; and c) 0.2 L. #: lower limit of 95% CI 60 s.*: p<0.05

High-intensity constant work-rate exercise tests

- Isotime response- Dyspnea
- 10-point Borg scale (CR-10)
- 100-mm visual analogue scale (VAS)
- Dyspnoea should be measured at rest when the patient is ready to exercise, at least every 2 min during the test and at end-exercise
- Neither iso time nor end-exercise dyspnoea scores have been specifically studied as predictive variables

Borg RPE Scale

Scoring	Level of Exertion
6	No Exertion
7	Extremely Light
8	
9	Very Light
10	
11	Light
12	
13	Somewhat Hard
14	
15	Hard (Heavy)
16	
17	Very Hard
18	
19	Extremely Hard
20	Maximal Exertion

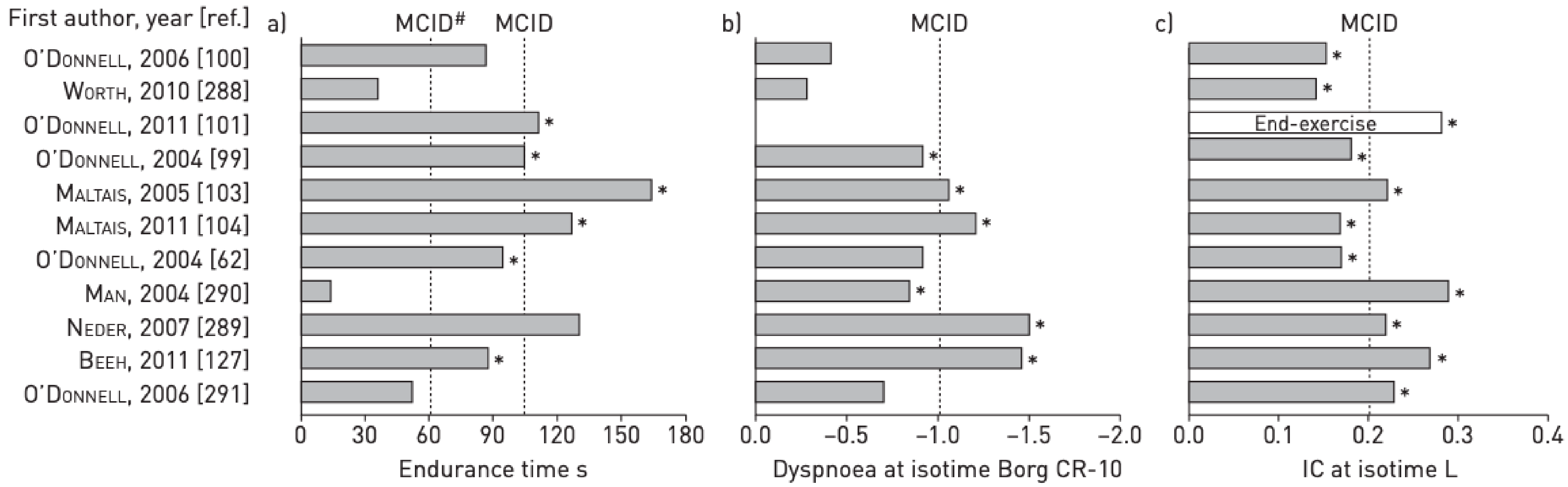
Borg CR10 Scale

Scoring	Level of Exertion
0	No Exertion
0.5	Very very Slight
1	Very Slight
2	Slight
3	Moderate
4	Somewhat Severe
5	Severe
6	
7	Very Severe
8	
9	Very very Severe
10	Maximal

- Am Rev Respir Dis. 1982;126(5):825–828
- J Emerg Nurs. 2000;26(3):216–222


At rest
No shortness of breath at all
Maximum shortness of breath
During activity
No shortness of breath at all
Maximum shortness of breath

High-intensity constant work-rate exercise tests



- Relationships between the changes in a) endurance time (time to the limit of tolerance (tLIM)); b) dyspnoea at iso time; and c) iso time inspiratory capacity (IC) after the administration of bronchodilators. Mean minimal clinically important difference (MCID) thresholds of a) 105 s; b) 1 point; and c) 0.2 L. #: lower limit of 95% CI 60 s.*: p<0.05

High-intensity constant work-rate exercise tests

- **Advantages**:
- Relatively expensive
- Can be performed without metabolic system
- Additional measurements easier on cycle

Take Home message

- Field test can be preferred over laboratory tests
- Limited evidence of ISWT and ESWT in disease other than COPD
- Minimally important difference (ISWT + ESWT) not clearly available for different disease
- Used in pre operative evaluation and response to treatment assessment
- Sensitivity, specificity not available for individual variables for diagnosing and differentiating disease