


Are the measurement properties of incremental exercise tests similar between patients with COPD and CHF?

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Abstract

We investigated whether the differences in exercise limitation between patients with chronic obstructive pulmonary disease (COPD) or chronic heart failure (CHF) affect the repeatability or responsiveness of incremental exercise tests. Patients with COPD (Medical Research Council dyspnoea grade 2–5) and patients with CHF (New York Heart Association class II–IV) performed two incremental shuttle walk tests (ISWT) following familiarisation and two incremental cycle ergometer tests (ICE) within 2 weeks. Both tests were repeated on completion of a pulmonary rehabilitation (PR) programme. One hundred and twelve patients were recruited. In response to exercise, patients with COPD were more likely than patients with CHF to have a ventilatory limitation ($p < 0.001$) and less likely to have a cardiovascular limitation ($p < 0.001$). The ISWT distance and ICE peak volume of oxygen uptake (VO_2Peak) were similarly repeatable ($p = 0.11$ and $p = 0.47$ for time and disease effect) and responsive to PR ($p = 0.44$ and $p = 0.67$) between diseases. There was no difference in repeatability or responsiveness with either a ventilatory or cardiovascular limitation to exercise ($p > 0.20$ for all comparisons). The coefficient of repeatability across the cohort was 60 m for the ISWT and 0.270 L/minute for ICE VO_2Peak . The minimum important difference (MID) for the ISWT in both diseases for PR was 30 m. The repeatability and responsiveness of the ISWT distance and ICE VO_2Peak are similar between patients with COPD and CHF and are unaffected by differences in exercise limitation. A change of 60 m in the ISWT or 0.270 L/minute in ICE VO_2Peak is required to be 95% certain that a true change has occurred within an individual patient. For a group of patients with either COPD or CHF, the MID for the ISWT distance is estimated to be 30 m.

Keywords

COPD, heart failure, exercise testing, pulmonary rehabilitation

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Introduction

Cardiovascular disease and chronic obstructive pulmonary disease (COPD) are priority non-communicable diseases.¹ Individuals with either chronic heart failure (CHF) or COPD suffer from similar symptoms of exertional dyspnoea and fatigue. The relationship between worsening primary organ impairment and worsening exercise capacity weakens with increasing severity of the primary organ impairment as deconditioning from physical inactivity

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becomes a greater determinant.^{2,3} Exercise training is an effective therapy for CHF⁴ and COPD⁵ by at least partially reversing the skeletal muscle impairments^{6,7} leading to improvements in exercise performance. International guidance for the management of both CHF and COPD recommend the use of exercise-based interventions to improve exercise performance, dyspnoea, health-related quality of life and reduce healthcare utilisation.^{8–10}

Patients with COPD and CHF can train effectively together using the same symptom-based exercise programme rather than the traditional disease-specific models of cardiac rehabilitation (CR) and pulmonary rehabilitation (PR).¹¹ There is interest in implementing combined exercise programmes,¹² and therefore a need to understand the measurement properties of any outcome measures between the populations. Both the incremental shuttle walking test (ISWT) and incremental cycle ergometry test (ICE) are validated measures of peak exercise capacity in COPD¹³ and CHF.¹⁴ Although both patients with COPD and CHF suffer from deconditioning and resultant skeletal muscle impairment, the precise limitation to exercise can be distinct. Patients with COPD frequently have a ventilatory limitation to exercise caused by a mechanical limitation through increasing operating lung volumes. This causes an abrupt halt at peak performance as inspiratory reserve volume is reached and intolerable tachypnoea and dyspnoea ensues. Peak performance may therefore be less variable. In contrast, the cardiovascular limitation to exercise seen in patients with CHF does not involve an increase in operating lung volumes, rather it is similar to the limitation seen in health (a further increase or sustained heart rate (HR) is unable to be tolerated) but at a lower level of peak oxygen uptake (VO_2Peak). It could be postulated that individual tolerance of symptoms may result in greater variability of peak performance. However, it is currently unknown if the measurement properties of the tests differ between the two populations.

The overall aim was therefore to compare the repeatability and responsiveness (measurement properties) of the ISWT and ICE between patients with COPD and CHF. We aimed to compare the exercise responses between COPD and CHF, and to describe the mechanisms of exercise limitation, that is, cardiovascular or ventilatory for each patient. We aimed to compare the measurement properties of the ISWT and ICE between the two different diseases and by the type of limitation to exercise. We hypothesised that

there would be no differences in the measurement properties of the ICE and the ISWT between the two chronic diseases despite any differences in the mechanism of limitation to exercise.

Materials and methods

Study design

The study protocol was approved by the Leicestershire Research Ethics Council (National Research Registry N0123134233). The results of the main study demonstrating that combined COPD and CHF exercise rehabilitation was feasible and effective are previously published.¹⁵ Data generated from this study were utilised to evaluate the repeatability and responsiveness of commonly used incremental exercise tests between patients with COPD and CHF.

Participants

Patients with a clinical diagnosis of COPD, supporting spirometry of a forced expiratory volume in 1 second/forced vital capacity (FEV_1/FVC) <70% and an FEV_1 <80% predicted and Medical Research Council dyspnoea scale 2–5 were eligible to participate. Patients with a clinical diagnosis of CHF were eligible to participate, New York Heart Association class II–IV and evidence of left ventricular dysfunction (left ventricular ejection fraction <40% on echocardiography). Patients with combined COPD and CHF were excluded after clinical assessment with spirometry and N-terminal brain natriuretic peptide (BNP) level, respectively. Where the latter was higher than the normal age and gender predicted range an echocardiogram was requested.¹¹ Other exclusion criteria were any significant co-morbidity severely limiting the ability to exercise or not being test naive which may affect repeatability.¹⁶ Written consent was obtained prospectively.

Pulmonary rehabilitation

Patients underwent a 7-week outpatient PR programme, involving twice weekly supervised sessions of exercise training (individually prescribed aerobic training predominantly by walking and at home) and education, previously described and in accordance with international guidance.¹¹ All patients with COPD were allocated to receive PR.¹⁷ The patients with CHF were randomised to PR or usual care; the baseline data for both groups have been combined for the repeatability analysis. The data from those who

were randomised to PR were included in the responsiveness analysis.

Outcomes

For baseline measures, patients completed the schedule of testing over four visits with at least 48 hours between visits; visit 1: baseline ICE1, visit 2: familiarisation ISWT and ISWT1, visit 3: second baseline ICE2 and visit 4: ISWT2. After a 7-week programme of PR, patients completed another ICE and ISWT on separate days. Randomisation of tests performed was not conducted as the completion of an ICE was required for patient safety and eligibility for inclusion in the study, and was therefore always the first test performed. Patients were excluded if they were already familiar with either test or they were unable to perform cycle ergometry due to musculoskeletal problems.

Patients performed a symptom-limited, maximal, ICE test on an electronically braked cycle tests ergometer with expired gas analysis using a step 10 W/minute protocol (Zan-680 Ergo Test; Zan Messgeraete GmbH, Oberthulba, Germany) to recommended guidelines.¹⁶ Non-invasive electrocardiography monitoring and pulse oximetry were continuously monitored. Measures of blood pressure were recorded before and after each test and at 2-minute intervals during the test alternately with the Borg scale of breathlessness (BS) and perceived exertion (PE) scores.

Patients were asked to avoid eating 4 hours before testing. The tests were performed at the same time of day and by the same operator. Patients were asked to cycle between 40 revolutions/minute and 80 revolutions/minute. Data were analysed using breath-by-breath analysis for outcomes of the VO_2Peak , peak ventilation (VEPeak) and respiratory exchange ratio. Patients were defined as ventilatory limited if the ratio of VEPeak divided by maximum voluntary ventilation (MVV) was >0.85 , where $\text{MVV} = \text{FEV}_1 (\text{L}) \times 37.5$.¹⁸ Cardiovascular limitation was defined as peak HR $>80\%$ of maximal predicted HR.¹⁹ Chronotropic incompetence occurs for patients prescribed a beta blocker²⁰ and for these patients HRPeak was calculated as recommended.²¹

The ISWT is a maximal, externally paced, symptom-limited test conducted along a 10 m course.²² The ISWT has been validated both in patients with CHF¹⁴ and with COPD¹³ and is reproducible after one practice test (familiarisation).²³

A familiarisation test was performed as per recommendations.²² Distance walked was recorded to the last 10 m completed along with the reason for termination. Measures of pulse oximetry and HR were recorded before and after each test along with the BS and PE scores.

Statistical analysis

Baseline demographic and exercise data were described as mean (standard deviation (SD)) or median (interquartile range) for normally and non-normally distributed continuous data, respectively. The comparison between patients with COPD and CHF of baseline demographic and exercise data was described using an independent *t*-test or Mann–Whitney *U* test for continuous data depending on normal distribution or not, respectively, and χ^2 test for categorical data. The coefficient of repeatability and its precision were calculated as described by Bland and Altman.²⁴ Intraclass correlation coefficients (ICCs) were calculated using Cronbach's α . The coefficient of variation was calculated by the within-subject SD divided by the mean.²⁵ A two-way analysis of covariance was performed for repeatability and responsiveness with time (either test 1 and 2 for repeatability, or before and after the intervention period for responsiveness), age, gender and disease as independent factors. A subsequent analysis was performed with either a ventilatory limitation or cardiovascular limitation as independent factors. Effect size (ES) of the intervention was calculated as Cohen's *d*. The minimum important difference (MID) was calculated as $0.5 \times$ the SD of the change using the distribution method.

Results

The demographics between patients with CHF ($n = 57$) and COPD ($n = 55$) were similar (Table 1) with differences in spirometry and BNP levels as expected. Fifty-two patients with COPD and 47 patients with CHF completed two ICE tests and ISWTs following familiarisation. The main reasons for exclusion were joint limitations for the ICE or patients were not test naive.

Comparison of the baseline exercise test results between COPD and CHF

The results of the ISWT and ICE between COPD and CHF are shown in Table 2. Peak performance was similar between the patients with COPD and CHF.

Table 1. Baseline demographics for patients with CHF and COPD.^a

	CHF (n = 57)	COPD (n = 55)
Age (years)	70.0 (10.18)	69.1 (8.3)
Sex (% male)	68.4%	54.4%
Smoking (pack year)	15.71 (20.65)	37.68 (19.72)
BMI (kg/m ²)	31.09 (6.40)	27.4 (5.2)
LVEF %	31.02 (9.98)	N/A
BNP (fmol/L)	723 (311–1928)	99 (57–251)
FEV ₁ /FVC	76.7 (4.8)	50.0 (8.7)
FEV ₁ % predicted	82 (21)	43 (15)
NYHA class for CHF	3	N/A
MRC dyspnoea grade for COPD	3	3

BMI: body mass index; LVEF: left ventricular ejection fraction; NYHA: New York Heart Association; FEV₁/FVC: forced expiratory volume in 1 second/forced vital capacity; BNP: N-terminal brain natriuretic peptide; MRC: Medical Research Council; COPD: chronic obstructive pulmonary disease; CHF: chronic heart failure; SD: standard deviation; IQR: interquartile range.

^amedian (IQR).

Patients with COPD more frequently had a ventilatory limitation to exercise than patients with CHF (57% vs. 2%, $p < 0.01$), but the limiting symptoms and their severity were similar between diseases. Patients with COPD showed greater desaturation with exercise whereas patients with CHF achieved a significantly lower peak HR for both tests (Table 2). Twenty-three percent of patients with CHF versus 2% of patients with COPD had a cardiovascular limitation to exercise ($p < 0.01$). There was a correlation between ISWT distance and ICE VO₂Peak for both COPD and CHF ($r = 0.63$ and 0.57 , $p < 0.01$, respectively).

Repeatability of ISWT and ICE

There was a mean (SD) increase of 20 (4) m between ISWT familiarisation and ISWT1 ($p < 0.001$). There was no difference between test 1 and 2 for either COPD or CHF for the ISWT (12 m, $p = 0.08$ and 1 m, $p = 0.77$) and ICE VO₂Peak (0.03 L/minute, $p = 0.08$ and 0.01 L/minute, $p = 0.69$, respectively) and no overall effect of disease ($p = 0.47$). Repeatability was similar between patients with or without a ventilatory limitation to exercise (ISWT 8.0 (24.0) m vs. 0.4 (32.0) m, respectively, $p = 0.53$ and ICE VO₂Peak 0.060 (0.124) L/minute vs. 0.006 (0.137) L/minute, $p = 0.41$), or with those with or without a cardiovascular limitation (ISWT 3 (32) m vs. 2 (28) m, $p = 0.63$ and ICE VO₂Peak 0.028 (0.149)

L/minute vs. 0.017 (0.132) L/minute, $p = 0.87$). Data were therefore combined. Figure 1 shows the repeatability of the ISWT and ICE VO₂Peak for patients with COPD and CHF. Overall, repeatability for the ISWT was 2 (30) m, $p = 0.521$, and for the ICE VO₂Peak 0.019 (0.134) L/minute, $p = 0.158$. The coefficient of repeatability for the ISWT and ICE VO₂Peak was 60 m and 0.270 L/minute, respectively. The precision of the coefficient of repeatability was ± 11 m for the ISWT and 0.047 L/minute for ICE VO₂Peak. The coefficient of variation was 7% for both tests and ICCs were high 0.95 and 0.97, respectively. Table 3 illustrates the physiological responses elicited between ISWT1 and 2 and ICE1 and 2 for all patients.

response of ISWT and ICE to PR

The mean change in ISWT for both COPD and CHF following PR has previously been reported¹¹ and a large ES observed. There was no difference in responsiveness between COPD ($n = 44$) and CHF ($n = 27$) for the ISWT or ICE VO₂Peak, $p = 0.44$ and $p = 0.67$ (Figure 2). The mean change (SD) ISWT distance for the whole cohort was 68 (60) m, ES (0.54), $p < 0.001$. The MID of the ISWT in COPD and CHF by the distribution method is therefore 30 m. There was only a small change in ICE VO₂Peak for the cohort 0.040 (0.016) L/minute, $p = 0.033$, ES (0.11). The responsiveness for both tests was unaltered by either the presence of a ventilatory limitation (ISWT distance 66 (66) m vs. 51 (63) m, respectively, $p = 0.85$ and ICE VO₂Peak 0.030 (0.154) L/minute vs. 0.041 (0.142) L/minute, respectively, $p = 0.58$) or a cardiovascular limitation (ISWT distance 51 (75) m vs. 56 (60) m, respectively, $p = 0.63$ and ICE VO₂Peak 0.023 (0.212) L/minute vs. 0.043 (0.199) L/minute, respectively, $p = 0.47$).

Discussion

We compared the measurement properties of the ISWT and the incremental cardiopulmonary exercise test performed on a cycle ergometer (ICE) between patients with symptomatic COPD or CHF. Despite differences in exercise responses, namely increased frequency of oxygen desaturation and ventilatory limitation to exercise in COPD group, the ISWT distance and ICE VO₂Peak were similarly repeatable in both populations. Our data showed no difference in the responsiveness to the intervention between either disease or the type of exercise limitation to exercise.

Table 2. A comparison of the physiological responses to the ISWT and ICE between patients with COPD and CHF.^a

Peak parameters	ISWT2			ICE2		
	COPD	CHF	<i>p</i>	COPD	CHF	<i>p</i>
Distance (m)	225 (115)	231 (135)	0.77	—	—	—
HR (bpm)	107 (18)	98 (22)	0.03	117 (19)	105 (25)	0.03
SpO ₂ (%)	88 (8)	94 (5)	<0.001	89 (8)	95 (4)	<0.001
End BS ^b	4 (4–7)	4 (3–5)	0.19	4 (4–5)	5 (3–5)	0.14
End PE ^b	15 (13–17)	15 (13–17)	0.98	15 (15–17)	17 (15–17)	0.38
Duration (second)	—	—	—	305 (118)	305 (163)	1.00
VO ₂ Peak (L/minute)	—	—	—	0.89 (0.29)	0.92 (0.36)	0.63
VCO ₂ Peak (L/minute)	—	—	—	0.87 (0.30)	0.95 (0.40)	0.24
VEPeak (L/minute)	—	—	—	32.20 (10.26)	40.79 (14.40)	<0.01
VE/MVV	—	—	—	0.84 (0.19)	0.50 (0.15)	<0.05
Ventilatory limitation % (Y)	—	—	—	57%	2%	<0.01
CVS limitation % (Y)	—	—	—	2%	23%	<0.01
RER	—	—	—	0.98 (0.07)	1.04 (0.10)	<0.001
Peak work (W)	—	—	—	51 (21)	51 (27)	1.00

SpO₂: oxygen pulse oximetry; BS: Borg breathlessness score; PE: perceived exertion score; VO₂Peak: peak oxygen uptake; VCO₂Peak: peak carbon dioxide production; VEPeak: peak ventilation; VE/MVV: peak ventilation/maximum voluntary ventilation; ventilatory limitation = >0.8 VE/MVV; RER: respiratory exchange ratio; ISWT2: baseline incremental shuttle walk test 2; ICE2: baseline incremental cycle ergometer test 2; COPD: chronic obstructive pulmonary disease; CHF: chronic heart failure; SD: standard deviation; IQR: interquartile range; HR: heart rate; CVS: cardiovascular.

^aData displayed as mean (SD) or median (IQR).

^bMedian (IQR).

We report, in over a hundred patients, stability of ICE VO₂Peak over 2 weeks in both COPD and CHF supported by high ICCs. Previous small studies have shown conflicting results regarding the repeatability of ICE VO₂Peak in COPD or CHF.²⁶ Part of a systematic review of exercise tests in patients with COPD²⁷ described four studies assessing the repeatability of ICE VO₂Peak over two tests ($n = 103$).^{28–31} Overall, there was no significant mean change ICE VO₂Peak between test 1 and test 2 (11–53 mL/minute, $p = \text{NS}$) consistent with our data. A further study showed progressive increases in exercise duration over four tests but VO₂Peak was not reported.³² Only one previous study has directly compared the reliability of cardiopulmonary exercise testing on a cycle ergometer in patients with cardiac or respiratory disease but the test protocol was different for each of the two tests.³³ The first test was a fixed 10 W/minute increment and the second a personalised ramp test; however, there was no mean difference in ICE VO₂Peak 24 (114) mL/minute between the two tests. The coefficient of variation was 9% slightly higher than we report when using the same protocol for both tests.

In smaller studies in specific diseases, the time between testing varied from same day,²⁸ consecutive

day^{30–32} or up to 2 weeks.^{29,34–36} Protocols also varied between an individualised approach of either 5 or 10 W,³⁰ and others employing a standard increment of between 10 W and 30 W. Only one study reported using a step protocol³⁰ and more often the type of protocol: step or ramp was not reported. We confirm stability of ICE VO₂Peak over 2 weeks using a step protocol. In our cohort, the specific disease did not alter the repeatability, and we report for the first time that ICE VO₂Peak is stable whether there is either a ventilatory or cardiac limitation to exercise despite the different mechanisms causing exercise termination. Overall, where VO₂Peak derived on a cycle ergometer is an outcome measure, full familiarisation testing is not required for patients with COPD or CHF even when cycling is an unfamiliar exercise.

We report the ISWT distance (after a single familiarisation test) to be repeatable with high reliability for patients with either COPD or CHF. Our data support international guidelines for COPD which recommend the use of a familiarisation test for the ISWT³⁷, as we found a significant increase from the familiarisation test to test 1 (20 ± 4 m) consistent with other studies either in CHF or COPD.^{23,38,39} Similar results with a significant learning effect of 29.5 m have been reported for a CR population.⁴⁰ Following an initial

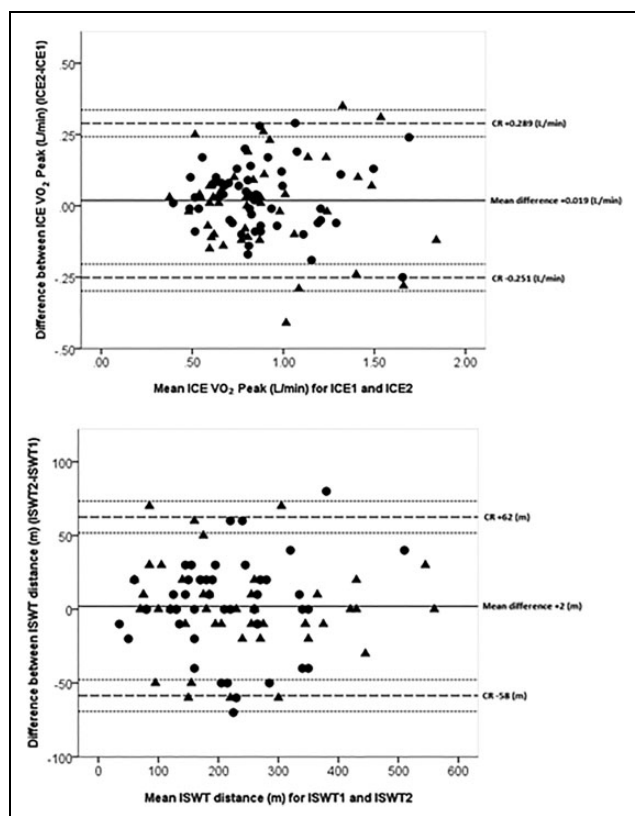


Figure 1. Repeatability of ICE VO_2Peak and ISWT distance for patients with COPD and CHF. The solid line represents the mean difference between the two tests, the dashed line represents the coefficient of repeatability and the dotted line shows the level of precision (95% CI) of the coefficient of repeatability. Disease is represented by triangles for CHF and circles for COPD. CR: coefficient of repeatability; ISWT: incremental shuttle walk test; ICE: incremental cycle ergometer test; VO_2Peak : peak oxygen uptake; ISWT1: Baseline incremental shuttle walk test I; ISWT2: second ISWT; ICE1: baseline ICE test; ICE2: second ICE; COPD: chronic obstructive pulmonary disease; CHF: chronic heart failure.

increase after familiarisation, the ISWT is similarly repeatable in both COPD and CHF^{22,39,41} and we report stability over 2 weeks. The stability of the ISWT distance was unaltered by disease or presence of either a ventilatory or cardiac limitation.

Our data highlight that the mean ISWT and ICE VO_2Peak are stable over time in patients with COPD or CHF. However, care is needed when interpreting data for a single individual in clinical practice. We report significant individual variability over time (without an intervention) for both the ISWT (60 m) and ICE VO_2Peak , (0.27 L/minute). The coefficient of repeatability for the 6-minute walk test (6MWT) is at least the same magnitude previously described at

82 m.²⁵ The individual variability is particularly relevant when individual responses to interventions are being used to directly inform clinical decisions, for example, response to pharmacological therapy.

We report that the magnitude of responsiveness of both tests is similar in both COPD and CHF tested under the same conditions by the same operators. There is little published data reporting the responsiveness ISWT in the heart failure population but it is responsive to CR in a typical cohort.⁴² A small study suggested significant improvements of 60 m in the ISWT after heart failure rehabilitation post-hospitalisation.⁴³ While systematic reviews have reported a positive response in ICE testing and the 6MWT, the ISWT has not been included.⁴⁴ However, the ISWT distance has been widely used in patients with COPD undergoing PR and average improvements reported between 36 m and 61 m.²⁷ We describe the MID for a group of patients with either COPD or CHF undergoing PR to be 30 m. The estimation of this MID, while not applicable for use at an individual level, is a useful statistical threshold for use when powering studies and reviewing service performance.

The ICE VO_2Peak has been more widely used in CHF rehabilitation than the ISWT and a recent systematic review demonstrated an overall response of 2.16 mL/kg/minute compared to usual care.⁴⁴ A systematic review and meta-analysis of PR versus usual care in COPD reported an increase in peak watts but did not report the effects on VO_2Peak .⁵ In our study, there was only a very small increase in ICE VO_2Peak following rehabilitation with a low ES in both populations. The differences in response of the ISWT distance and ICE VO_2Peak in our study may be explained by the difference in test platform compared to the modality of training.

We have specifically evaluated the peak measurements derived from the ISWT and a cardiopulmonary exercise test on a cycle ergometer as these are the most widely used outcome measures. We did not perform expiratory gas analysis for the ISWT; however, the validity of the ISWT distance compared to laboratory CPET (cardiopulmonary exercise test) has been described previously for both populations although on a treadmill rather than a cycle ergometer.^{39,45,46}

The possibility of a type II error cannot be excluded; however, for the majority of comparisons, the numerical values were similar for repeatability and responsiveness for both tests regardless of disease or precise limitation to exercise. It is therefore less likely that we are missing a meaningful difference.

Table 3. Physiological response to exercise testing at baseline.

Peak parameters	ISWT			ICE		
	ISWT1	ISWT2	<i>p</i>	ICE1	ICE2	<i>p</i>
Distance (m)	219 (115)	221 (115)	0.52	N/A	N/A	–
Duration (second)	N/A	N/A	–	287 (139)	297 (136)	0.17
HR (bpm)	104 (1.9)	103 (2.1) ^b	0.89	110 (23)	111 (24) ^b	0.39
SpO ₂ (%)	91 (7)	91 (7)	0.72	92 (7)	92 (7)	0.82
End BS ^a	4 (4–5)	4 (3–5)	0.30	4 (4–5)	4.5 (4.5–6.3)	0.08
End PE ^a	15 (13–17)	15 (13–17)	0.29	15 (15–17)	16 (15–17)	0.24
VO ₂ Peak (L/minute)	N/A	N/A	–	0.87 (0.319)	0.89 (0.313)	0.16
VCO ₂ Peak (L/minute)	N/A	N/A	–	0.86 (0.35)	0.89 (0.34)	0.10
VEPeak (L/minute)	N/A	N/A	–	30.69 (10.50)	31.65 (10.16)	0.15
RER	N/A	N/A	–	0.98 (0.10)	1.00 (0.09)	<0.001
Peak work (W)	N/A	N/A	–	48 (24)	50 (23)	0.09

HR: heart rate; SpO₂: oxygen pulse oximetry; BS: Borg breathlessness score; PE: perceived exertion score; VO₂Peak: peak oxygen uptake; VCO₂Peak: peak carbon dioxide production; VEPeak: peak ventilation; RER: respiratory exchange ratio; ISWT: baseline incremental shuttle walk test; ICE: baseline incremental cycle ergometer test; SD: standard deviation; IQR: interquartile range.

^aMedian (IQR).

^bDifference between ISWT2 and ICE2, *p* < 0.001.

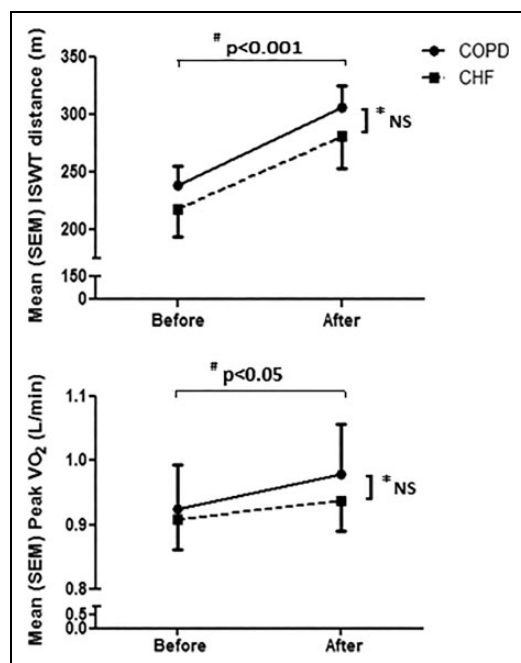


Figure 2. Responsiveness of the ISWT distance (m) and ICE VO₂Peak (L/minute) to PR between patients with COPD or heart failure. Disease is represented by a solid line with circles for COPD and squares with a dashed line for CHF. # represents intragroup difference and * represents intergroup difference. SEM: standard error mean; ISWT: incremental shuttle walk test; ICE: incremental cycle ergometer test; VO₂Peak: peak oxygen uptake; PR: pulmonary rehabilitation; COPD: chronic obstructive pulmonary disease; CHF: chronic heart failure.

We have also provided the precision of the coefficient of repeatability which shows narrow 95% confidence intervals.

We provide novel information on two commonly used incremental exercise tests to help clinicians and researchers accurately interpret the results of these tests after an intervention to understand if a true change has occurred both in an individual patient and for a group. Healthcare provision is starting to be organised around symptoms for example breathlessness rather than specific diseases and will be aided by having well-validated outcome measures across different disease populations. Although we describe the MID of the ISWT by distribution method, the relatively small sample size is noted.

Conclusion

Our data demonstrate that the ISWT distance (after familiarisation) and ICE VO₂Peak are similarly repeatable, reliable and responsive measures for patients with COPD or CHF despite their different exercise responses. A change of 60 m in the ISWT distance or 0.270 L/minute in ICE VO₂Peak is required in clinical practice to be 95% certain that a true change has occurred within an individual patient. The ISWT distance was more responsive than the ICE VO₂Peak in both conditions. For a group of patients

with either COPD or CHF undergoing PR, the MID in ISWT distance is estimated to be 30 m.

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References

1. Global Burden of Disease Study 2013 Collaborators. Global, regional, and national incidence, prevalence, and years lived with disability for 301 acute and chronic diseases and injuries in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2015; 386(9995): 743–800.
2. Gosker HR, Lencer NH, Franssen FM, et al. Striking similarities in systemic factors contributing to decreased exercise capacity in patients with severe chronic heart failure or COPD. *Chest* 2003; 123(5): 1416–1424.
3. Gosker HR, Wouters EF, van der Vusse GJ, et al. Skeletal muscle dysfunction in chronic obstructive pulmonary disease and chronic heart failure: underlying mechanisms and therapy perspectives. *Am J Clin Nutr* 2000; 71(5): 1033–1047.
4. Sagar VA, Davies EJ, Briscoe S, et al. Exercise-based rehabilitation for heart failure: systematic review and meta-analysis. *Open Heart* 2015; 2(1): e000163.
5. McCarthy B, Casey D, Devane D, et al. Pulmonary rehabilitation for chronic obstructive pulmonary disease. *Cochrane Database Syst Rev* 2015; 2: CD003793.
6. Hambrecht R, Fiehn E, Yu J, et al. Effects of endurance training on mitochondrial ultrastructure and fiber type distribution in skeletal muscle of patients with stable chronic heart failure. *J Am Coll Cardiol* 1997; 29(5): 1067–1073.
7. Maltais F, LeBlanc P, Simard C, et al. Skeletal muscle adaptation to endurance training in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1996; 154(2 Pt 1): 442–447.
8. Writing Committee Members, Yancy CW, Jessup M, et al. 2013 ACCF/AHA guideline for the management of heart failure: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. *Circulation* 2013; 128(16): e240–327.
9. Global Initiative for Chronic Obstructive Lung Disease (GOLD). The Global Strategy for the Diagnosis, Management and Prevention of COPD, 2019. <https://goldcopd.org/gold-reports/> (accessed 1 October 2019).
10. Taylor R S, Sagar V A, Davies E J, et al. Exercise-based rehabilitation for heart failure. *Cochrane Database Syst Rev* 2014; 4: CD003331.
11. Evans RA, Singh SJ, Collier R, et al. Generic, symptom based, exercise rehabilitation; integrating patients with COPD and heart failure. *Respir Med* 2010; 104(10): 1473–1481.
12. Man WD, Chowdhury F, Taylor RS, et al. Building consensus for provision of breathlessness rehabilitation for patients with chronic obstructive pulmonary disease and chronic heart failure. *Chron Respir Dis* 2016; 13(3): 229–239.
13. Singh SJ, Morgan MD, Hardman AE, et al. Comparison of oxygen uptake during a conventional treadmill test and the shuttle walking test in chronic airflow limitation. *Eur Respir J* 1994; 7(11): 2016–2020.
14. Keell SD, Chambers JS, Francis DP, et al. Shuttle-walk test to assess chronic heart failure. *Lancet* 1998; 352(9129): 705.
15. Evans RA. *Generic exercise rehabilitation for patients with chronic obstructive pulmonary disease and chronic heart failure*. Leicester: University of Leicester, 2009.
16. American Thoracic Society, American College of Chest Physicians. ATS/ACCP statement on cardiopulmonary exercise testing. *Am J Respir Crit Care Med* 2003; 167(2): 211–277.
17. Bolton CE, Bevan-Smith EF, Blakey JD, et al. British Thoracic Society guideline on pulmonary rehabilitation in adults. *Thorax* 2013; 68: ii1–30.

18. Cooper CB and Storer TW. *Exercise testing and interpretation: a practical approach*. Cambridge/New York: Cambridge University Press, 2001, pp. 278.
19. Astrand I. Aerobic work capacity in men and women with special reference to age. *Acta Physiol Scand Suppl* 1960; 49(169): 1–92.
20. Balady GJ, Arena R, Sietsema K, et al. Clinician's guide to cardiopulmonary exercise testing in adults: a scientific statement from the American Heart Association. *Circulation* 2010; 122(2): 191–225.
21. Beale L, Carter H, Doust J, et al. Exercise heart rate guidelines overestimate recommended intensity for chronic heart failure patients. *Br J Cardiol* 2010; 17: 133–137.
22. Singh SJ, Morgan MD, Scott S, et al. Development of a shuttle walking test of disability in patients with chronic airways obstruction. *Thorax* 1992; 47(12): 1019–1024.
23. Green DJ, Watts K, Rankin S, et al. A comparison of the shuttle and 6 minute walking tests with measured peak oxygen consumption in patients with heart failure. *J Sci Med Sport* 2001; 4(3): 292–300.
24. Bland JM and Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; 1(8476): 307–310.
25. Dolmage TE, Hill K, Evans RA, et al. Has my patient responded? Interpreting clinical measurements such as the 6-minute-walk test. *Am J Respir Crit Care Med* 2011; 184(6): 642–646.
26. ERS Task Force, Palange P, Ward SA, et al. Recommendations on the use of exercise testing in clinical practice. *Eur Respir J* 2007; 29(1): 185–209.
27. Fotheringham I, Meakin G, Puneekar YS, et al. Comparison of laboratory- and field-based exercise tests for COPD: a systematic review. *Int J Chron Obstruct Pulmon Dis* 2015; 10: 625–643.
28. Brown SE, Fischer CE, Stansbury DW, et al. Reproducibility of VO₂max in patients with chronic air-flow obstruction. *Am Rev Respir Dis* 1985; 131(3): 435–438.
29. Covey MK, Larson JL, Alex CG, et al. Test-retest reliability of symptom-limited cycle ergometer tests in patients with chronic obstructive pulmonary disease. *Nurs Res* 1999; 48(1): 9–19.
30. Cox NJ, Hendriks JC, Binkhorst RA, et al. Reproducibility of incremental maximal cycle ergometer tests in patients with mild to moderate obstructive lung diseases. *Lung* 1989; 167(2): 129–133.
31. Mathur RS, Revill SM, Vara DD, et al. Comparison of peak oxygen consumption during cycle and treadmill exercise in severe chronic obstructive pulmonary disease. *Thorax* 1995; 50(8): 829–833.
32. Swinburn CR, Wakefield JM and Jones PW. Performance, ventilation, and oxygen consumption in three different types of exercise test in patients with chronic obstructive lung disease. *Thorax* 1985; 40(8): 581–586.
33. Barron A, Dhutia N, Mayet J, et al. Test-retest repeatability of cardiopulmonary exercise test variables in patients with cardiac or respiratory disease. *Eur J Prev Cardiol* 2014; 21(4): 445–453.
34. Marburger CT, Brubaker PH, Pollock WE, et al. Reproducibility of cardiopulmonary exercise testing in elderly patients with congestive heart failure. *Am J Cardiol* 1998; 82(7): 905–909.
35. Meyer K, Westbrook S, Schwaibold M, et al. Short-term reproducibility of cardiopulmonary measurements during exercise testing in patients with severe chronic heart failure. *Am Heart J* 1997; 134(1): 20–26.
36. Valy Y, Coisne D, Ingrand P, et al. Reproducibility of measurements of blood gas exchange during exercise in mild cardiac failure: need for a preliminary test? *Arch Mal Coeur Vaiss* 1997; 90(4): 477–482.
37. Holland AE, Spruit MA, Troosters T, et al. An official European Respiratory Society/American Thoracic Society technical standard: field walking tests in chronic respiratory disease. *Eur Respir J* 2014; 44(6): 1428–1446.
38. Pulz C, Diniz RV, Alves ANF, et al. Incremental shuttle and six-minute walking tests in the assessment of functional capacity in chronic heart failure. *Can J Cardiol* 2008; 24(2): 131–135.
39. Morales FJ, Martínez A, Méndez M, et al. A shuttle walk test for assessment of functional capacity in chronic heart failure. *Am Heart J* 1999; 138(2): 291–298.
40. Jolly K, Taylor RS, Lip GY, et al. Reproducibility and safety of the incremental shuttle walking test for cardiac rehabilitation. *Int J Cardiol* 2008; 125(1): 144–145.
41. Eiser N, Willsher D and Dore CJ. Reliability, repeatability and sensitivity to change of externally and self-paced walking tests in COPD patients. *Respir Med* 2003; 97(4): 407–414.
42. Robinson HJ, Samani NJ and Singh SJ. Can low risk cardiac patients be 'fast tracked' to Phase IV community exercise schemes for cardiac rehabilitation? A randomised controlled trial. *Int J Cardiol* 2011; 146(2): 159–163.

-
43. Houchen L, Watt A, Boyce S, et al. A pilot study to explore the effectiveness of “early” rehabilitation after a hospital admission for chronic heart failure. *Physiother Theory Pract* 2012; 28(5): 355–358.
 44. Rees K, Taylor RS, Singh S, et al. Exercise based rehabilitation for heart failure. *Cochrane Database Syst Rev* 2004; 3(3): CD003331.
 45. Luxton N, Alison JA, Wu J, et al. Relationship between field walking tests and incremental cycle ergometry in COPD. *Respirology* 2008; 13(6): 856–862.
 46. Palange P, Forte S, Onorati P, et al. Ventilatory and metabolic adaptations to walking and cycling in patients with COPD. *J Appl Physiol* 2000; 88(5): 1715–1720.