A multicentre validation of the 1-min sit-to-stand test in patients with COPD

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The 1-min STS test is a reliable, valid and responsive exercise capacity test in COPD with an MID of 3 repetitions http://ow.ly/teNx307ni0Q

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ABSTRACT Our aim was to comprehensively validate the 1-min sit-to-stand (STS) test in chronic obstructive pulmonary disease (COPD) patients and explore the physiological response to the test.

We used data from two longitudinal studies of COPD patients who completed inpatient pulmonary rehabilitation programmes. We collected 1-min STS test, 6-min walk test (6MWT), health-related quality of life, dyspnoea and exercise cardiorespiratory data at admission and discharge. We assessed the learning effect, test–retest reliability, construct validity, responsiveness and minimal important difference of the 1-min STS test.

In both studies (n=52 and n=203) the 1-min STS test was strongly correlated with the 6MWT at admission (r=0.59 and 0.64, respectively) and discharge (r=0.67 and 0.68, respectively). Intraclass correlation coefficients (95% CI) between 1-min STS tests were 0.93 (0.83–0.97) for learning effect and 0.99 (0.97–1.00) for reliability. Standardised response means (95% CI) were 0.87 (0.58–1.16) and 0.91 (0.78–1.07). The estimated minimal important difference was three repetitions. End-exercise oxygen consumption, carbon dioxide output, ventilation, breathing frequency and heart rate were similar in the 1-min STS test and 6MWT.

The 1-min STS test is a reliable, valid and responsive test for measuring functional exercise capacity in COPD patients and elicited a physiological response comparable to that of the 6MWT.

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Introduction

Commonly used and well-established exercise capacity tests in chronic obstructive pulmonary disease (COPD), such as the 6-min walk test (6MWT) [1] and incremental shuttle walk test [2] are not often assessed in inpatient, specialist outpatient or primary care settings due to the time, space and resources required to conduct them [3]. Since these settings are where most COPD patients are seen by practitioners, many patients are not able to have their exercise capacity assessed.

In recent years, research has begun to investigate the development of alternative tests that are simpler and easier to conduct. Tests have been proposed that measure a sit-to-stand (STS) movement, which is a movement commonly performed in everyday life. Two main types of STS tests have been developed that measure either the number of repetitions performed in a set time, such as the 1-min STS test, or the time taken to perform a set number of repetitions, such as the five-repetition (5)STS test [4]. Previous research has found cross-sectional 1-min STS test scores to correlate well with the 6MWT [3] and quadriceps muscle strength [5–7], and moderately with physical activity [8], indicating that the 1-min STS test may have cross-sectional validity as a measure of exercise capacity. The 1-min STS test also has potential as an important predictive tool, having shown predictive validity as a strong and independent predictor of mortality and health-related quality of life (HRQoL) in COPD patients [9].

While the 1-min STS test is increasingly used in studies of COPD patients [8, 10–16], its learning effect, reliability, responsiveness to change and minimal important difference (MID) have not yet been established in this patient population. Furthermore, little is known about the physiological response to the 1-min STS test in terms of the cardiorespiratory stress elicited. Therefore, our aims were to comprehensively validate the 1-min STS test in COPD patients by assessing the learning effect, test–retest reliability, construct cross-sectional and longitudinal validity, responsiveness to change and MID, and to examine the physiological response to the 1-min STS test and compare it with those of the 6MWT and 5STS test.

Methods

For the in-depth validation of the 1-min STS, we conducted the Validation of the 1-minute Sit-to-Stand Test in Patients with COPD (STAND-UP) study and used data from a subsample of the Routine Inspiratory Muscle Training Within COPD Rehabilitation (RIMTCORE) study for additional information on validity, responsiveness and MID. Both studies were approved by local ethics committees (Kantonale Ethikkommission Zürich (2014-0614), Ethikkommission Nordwest- und Zentralschweiz (2015-095) and Ethik-Kommission der Bayerischen Landesärztekammer (12107)). Exercise capacity, quadriceps strength, HRQoL, health status and symptoms were assessed at admission and discharge in COPD patients admitted to inpatient pulmonary rehabilitation. Further details on the methods are provided in the online supplementary material.

Study design, participants and measurements

STAND-UP study

STAND-UP is a prospective multicentre study conducted in two Swiss pulmonary rehabilitation clinics (Clinic Barmelweid and Zürcher RehaZentrum Wald) (ClinicalTrials.gov: NCT02441725). Exclusion criteria were lower limb joint surgery in the preceding 3 months, predominant neurological or musculoskeletal limitation to walking, and inability to do five repetitions in the 1-min STS test. Functional exercise capacity (1-min STS test, 5STS and 6MWT), quadriceps maximal voluntary contraction (QMVC), HRQoL and health status (Chronic Respiratory Questionnaire (CRQ) [17, 18], COPD Assessment Test (CAT) [19] and feeling thermometer [20]) and symptoms (Hospital Anxiety and Depression Scale (HADS) [21] and Baseline and Transition Dyspnoea Indexes (BDI and TDI, respectively)) [22] were assessed at admission and discharge. All patients, except those unable to wear a face mask due to long-term oxygen therapy or other reasons, conducted additional exercise capacity tests using a metabolic cart (Cortex Metamax 3B, Leipzig, Germany) [23] measuring oxygen consumption ($V'_{\mathrm{O_2}}$), carbon dioxide output ($V'_{\mathrm{CO_2}}$), respiratory exchange ratio (RER), minute ventilation (V'_{E}), tidal volume (V_{T}), respiratory frequency (f_{R}), heart rate (HR) and arterial oxygen saturation measured by pulse oximetry ($S_{\mathrm{pO_2}}$) during rest, exercise and recovery.

1-min STS test protocol

All 1-min STS tests were performed according to a standardised protocol by trained study staff. We used a standard chair (height 46–48 cm) with a flat seat and no armrests, stabilised against a wall. Patients were asked to sit with their legs hip-width apart and flexed to 90°, with their hands stationary on the hips without using the hands or arms to assist movement. They were instructed to stand completely straight and touch the chair with their bottom when sitting, but that they need not sit fully back on the chair. Patients were asked to perform as many repetitions as possible in 1 min, and after 45 s were told “you have 15 s left until the test is over”.

RIMTCORE study

The RIMTCORE study is a randomised controlled trial (RCT) (German Clinical Trials Register: DRKS 00004609) to assess the impact of inspiratory muscle training in addition to standard pulmonary rehabilitation in 611 COPD patients from the German pulmonary rehabilitation clinic Bad Reichenhall. Further information and initial results have been published in abstract form [24]. We included 203 participants of the RIMTCORE study as a subsample who additionally completed the 1-min STS test at admission or discharge from pulmonary rehabilitation. The 1-min STS test was introduced as an additional assessment in the final third of the study, and from then on was routinely and consecutively assessed in all participants. Patients were assessed for exercise capacity (6MWT), HRQoL (CAT, St George's Respiratory Questionnaire (SGRQ) [25] and Clinical COPD Questionnaire (CCQ) [26]) and symptoms (Medical Research Council (MRC) dyspnoea scale [27] and BDI/TDI) at admission and discharge. The protocol for the 1-min STS test was similar to the STAND-UP study protocol.

Statistical analysis

Descriptive data were reported as mean±SD or numbers and proportions. We calculated intraclass correlation coefficients (ICCs) for random-effects models between consecutive 1-min STS tests (learning effect and test–retest reliability), Pearson correlation coefficients for 1-min STS test scores and change scores with measures previously validated in COPD patients (cross-sectional and longitudinal construct validity) and standardised response means (SRMs) for the 1-min STS test (responsiveness) [28]. We constructed a Bland–Altman plot to further assess test–retest reliability. The MID was estimated using a combination of anchor-based (linear regression with the 1-min STS change score as the dependent variable and anchor change score as the independent variable to derive a regression equation that estimates the change in 1-min STS test repetitions equivalent to the MID of the anchor) [29] and distribution-based (Cohen's effect size [30], empirical rule effect size [31] and standard error of measurement [32]) approaches. For the physiological response, breath-by-breath data were exported from the metabolic cart and averaged over 10 s. We calculated end-exercise values as the mean of the final 10 s of exercise for the 1-min STS test, the mean of the final 30 s for the 6MWT, and the mean of the final two breaths of exercise and the breath immediately after for the 5STS, using the breath-by-breath data due to the short exercise duration. We calculated rest values as 30-s averages between minutes 1:30 and 2:00 and recovery values as the final 30 s of recovery. For patients who performed a maximal cycle ergometry test at baseline, we calculated the mean HR at peak exercise during cycle ergometry, 1-min STS test and 6MWT. The required sample size for STAND-UP was calculated as 43 participants assuming a power of 0.9 to detect a difference of 4.4 (half the SD of 1-min STS test scores from a previous study) [9]. For the RIMTCORE subsample we performed a *post hoc* power calculation based on the sample size available for 1-min STS test change scores (n=188), giving an estimated power of 1.0. All analyses were conducted using Stata (version 14.1; StataCorp, College Station, TX, USA) and graphs produced using R (version 3.3.0; www.r-project.org).

Results

52 consecutive patients were included in the STAND-UP study and 48 patients completed follow-up assessments. Four patients withdrew from the study due to unwillingness to continue or early discharge. 203 patients were included as a subsample of the RIMTCORE study with data for both assessment points available for 188. Baseline characteristics for both studies are shown in table 1, and baseline, follow-up and change scores for the exercise capacity tests, QMVC and patient-reported outcomes are shown in table 2.

TABLE 1 Baseline characteristics of patients in the STAND-UP and RIMTCORE studies

	STAND-UP	RIMTCORE
Age years	65.2±9.0	57.2±7.8
FEV_1 % predicted	40.6±14.7	56.1±14.7
BMI $kg \cdot m^{-2}$	24.2±5.6	27.2±6.5
Male	33 (63)	136 (67)
GOLD category		
II	15 (28.9)	109 (53.7)
III	17 (32.7)	78 (38.4)
IV	20 (38.5)	16 (7.9)
LTOT	24 (46.2)	18 (8.9)

Data are presented as mean±SD or n (%). FEV_1: forced expiratory volume in 1 s; BMI: body mass index; GOLD: Global Initiative for Chronic Obstructive Lung Disease; LTOT: long-term oxygen therapy.

TABLE 2 Mean scores for exercise capacity tests, muscle strength test and patient-reported outcomes, at baseline and follow-up and change after pulmonary rehabilitation

	Baseline	Follow-up	Change
STAND-UP			
Subjects	52	48	48
1st 1-min STS test reps	15.3±6.2	19.8±7.8	4.3±4.1
2nd 1-min STS test reps	16.4±6.9	20.2±7.8	3.8±3.9
Higher 1-min STS test reps	16.5±6.6	20.4±7.9	3.6±4.1
6MWT m	286.5±127.6	367.2±130.8	90.0±65.2
5STS s	13.5±8.8	10.1±4.3	2.2±4.1
QMVC# kg	25.1±7.6	29.3±9.2	3.6±5.2
CAT	18.6±7.0	15.2±6.6	−3.8±5.5
CRQ			
Dyspnoea	3.4±1.2	4.5±1·2	1.2±1.0
Fatigue	3.7±1.3	4.9±1.0	1.2±1.1
Emotional	4.1±1.4	5.3±1.1	1.3±1.1
Mastery	4.2±1.6	5.3±1.3	1.2±1.1
HADS anxiety	7.1±4.2	5.2±4.0	2.1±2.8
HADS depression	6.5±3.8	5.1±3.7	1.7±2.6
Feeling thermometer	52.4±14.9	63.0±14.8	10.3±16.7
BDI/TDI¶	4.7±2.1		4.5±3.4
RIMTCORE			
Subjects	200	191	188
1-min STS test reps	24.2±7.5	28.3±8.0	4.0±4.3
6MWT+ m	440.6±109.2	528.7±104.8	84.5±55.8
CAT	20.3±7.1	16.2±7.2	−4.0±5.8
SGRQ			
Symptoms	64.9±22.0	48.6±23.2	−16.1±21.6
Activity	61.5±19.5	52.7±23.2	−8.5±14.7
Impacts	38.6±18.9	27.7±17.8	−10.4±14.2
Total	50.1±17.4	39.0±18.0	−10.6±12.6
CCQ			
Symptoms	3.0±1.3	2.2±1.2	−0.7±1.1
Functional	2.8±1.2	2.1±1.2	−0.6±1.0
Mental	2.7±1.7	2.0±1.6	−0.7±1.5
Total	2.8±1.1	2.1±1.1	−0.7±0.9
BDI/TDI¶	6.2±2.5		4.8±3.2
MRC	2.5±1.2	2.2±1.3	−0.3±1.0

Data are presented as n or mean±SD. 1-min STS test: 1-min sit-to-stand test; 6MWT: 6-min walk test; 5STS: five-repetition sit-to-stand test; QMVC: quadriceps maximal voluntary contraction; CAT: COPD (chronic obstructive pulmonary disease) Assessment Test; CRQ: Chronic Respiratory Questionnaire; HADS: Hospital Anxiety and Depression scale; BDI/TDI: Baseline and Transition Dyspnoea Indexes; SGRQ: St George's Respiratory Questionnaire; CCQ: Clinical COPD Questionnaire; MRC: Medical Research Council dyspnoea scale. #: n=30; ¶: BDI: baseline score, TDI: change score; +: higher score of two tests was used.

After pulmonary rehabilitation, 1-min STS test scores improved by 3.6±4.1 (STAND-UP) and 4.0±4.3 (RIMTCORE).

Measurement properties

Learning effect and test–retest reliability

The mean increase in 1-min STS test scores at baseline (learning effect) was 0.8±2.2 repetitions and the ICC was 0.93 (95% CI 0.83–0.97). The mean difference between the two tests at follow-up (test–retest reliability) was 0.02±1.6 repetitions and the ICC was 0.99 (95% CI 0.97–1.00). A Bland–Altman plot for the difference in 1-min STS test scores at follow-up is shown in online supplementary figure S1.

Construct (convergent) validity

Correlation coefficients between the 1-min STS test and validation measures are presented in table 3, according to whether they fulfilled our *a priori* assumptions about strength of correlation. The magnitude of cross-sectional correlations between the 1-min STS test and exercise capacity tests (6MWT and 5STS) ranged from 0.59 to 0.70; QMVC and domains of HRQoL and health status instruments (CRQ, CAT, feeling thermometer, CCQ and SGRQ) ranged from 0.01 to 0.52; and symptoms instruments (HADS, BDI

TABLE 3 Pearson correlation coefficients for the 1-min sit-to-stand (STS) test with other exercise capacity tests, muscle strength test and patient-reported outcomes at admission, discharge and change scores[#]

	STAND-UP			RIMTCORE		
	Baseline	**Follow-up**	**Change**	**Baseline**	**Follow-up**	**Change**
Subjects n	52	48	48	200	191	188
6MWT[¶]	**0.59**	**0.67**	−0.08	**0.64**	**0.68**	0.21
5STS	**−0.59**	**−0.70**	−0.27			
QMVC[+]	**0.43**	**0.49**	0.24			
CRQ						
Dyspnoea	**0.27**	0.52	**0.15**			
Fatigue	**−0.01**	**0.33**	**0.17**			
Emotional	**0.07**	**0.38**	**0.11**			
Mastery	**0.09**	**0.28**	**0.18**			
CAT	**−0.20**	**−0.33**	**−0.25**	**−0.30**	**−0.30**	**−0.14**
HADS depression	**−0.13**	**−0.29**	**−0.20**			
HADS anxiety	**−0.03**	**−0.30**	**−0.22**			
Feeling thermometer	**0.12**	**0.38**	**0.35**			
BDI/TDI[§]	**0.51**		0.35	**0.43**		**−0.12**
SGRQ						
Symptoms				**−0.18**	**−0.27**	**−0.11**
Activity				−0.48	−0.44	**−0.12**
Impacts				**−0.32**	**−0.34**	**−0.19**
Total				**−0.38**	−0.42	**−0.21**
CCQ						
Symptoms				**−0.14**	**−0.18**	**−0.13**
Functional				−0.41	**−0.37**	**−0.05**
Mental				**−0.16**	**−0.21**	**−0.05**
Total				**−0.30**	**−0.31**	**−0.11**
MRC				−0.39	**−0.42**	−0.06

6MWT: 6-min walk test; 5STS: five-repetition sit-to-stand test; QMVC: quadriceps maximal voluntary contraction; CRQ: Chronic Respiratory Questionnaire; CAT: COPD (chronic obstructive pulmonary disease) Assessment Test; HADS: Hospital Anxiety and Depression scale; BDI/TDI: Baseline and Transition Dyspnoea Indexes; SGRQ: St George's Respiratory Questionnaire; CCQ: Clinical COPD Questionnaire; MRC: Medical Research Council dyspnoea scale. #: *a priori* assumption that correlations would be strong (⩾0.6) for exercise capacity tests (6MWT and 5STS), moderate (0.4–0.6) for muscle strength and dyspnoea (QMVC, BDI/TDI and MRC) and weak (<0.4) for health-related quality of life (CRQ, CAT, HADS, feeling thermometer, SGRQ and CCQ). Correlation coefficients are presented in bold when they met our assumptions and normal font when they were higher or lower than expected. ¶: for RIMTCORE, the higher score of two tests was used; +: n=30 (only conducted in one pulmonary rehabilitation clinic); §: BDI: baseline score, TDI: change score.

TABLE 4 Anchor- and distribution-based estimates of the minimal important difference (MID) for the 1-min sit-to-stand (STS) test

	Subjects n	**MID of anchor**	**Patients with change ⩾anchor MID n (%)**	**MID estimate[¶] (95% CI)**
Anchor approach[#]				
Feeling thermometer	46	5	32 (70)	3.19 (1.49–4.89)
TDI	44	1	44 (100)	2.11 (−0.13–4.34)

Distribution approaches	**STAND-UP**	**RIMTCORE**
SEM	0.93	
Cohen's effect size	1.80	2.16
Empirical rule effect size	1.99	2.07

TDI: Transition Dyspnoea Index; SEM: standard error of measurement. #: measures were considered as anchors when the change score correlation with the 1-min STS test was ⩾0.3; ¶: MID estimate= $\alpha+\beta_{anchor}\times$anchor MID.

and MRC dyspnoea scale) ranged from 0.03 to 0.51. In most cases, correlations were stronger at discharge than admission. Longitudinal correlations for change scores were all <0.4.

Responsiveness to change and MID

The SRM was 0.87 (95% CI 0.58–1.16) for STAND-UP and 0.91 (0.78–1.07) for the RIMTCORE subsample. The MID estimates are summarised in table 4. The anchor-based estimates were larger than the distribution-based estimates with the anchors feeling thermometer and TDI giving estimates of 3.19 and 2.11 repetitions, respectively. The distribution-based estimates were similar across both studies with estimates between 0.93 and 2.16 repetitions.

Physiological response

21 patients performed an additional 1-min STS test and 5STS with cardiorespiratory gas analysis, and 15 of those performed the 6MWT in addition. Reasons for missing 6MWTs were technical problems with the metabolic cart (n=4), logistical problems (n=1) or unwillingness to wear the facemask (n=1). For the 21 patients, mean±SD age was 64.5±9.7 years, forced expiratory volume in 1 s was 47.3±14.2% predicted, body mass index was 23.5±5.0 $kg \cdot m^{-2}$ and 15 (71%) were male.

Table 5 summarises the physiological values at rest, end-exercise and recovery for each exercise capacity test. End-exercise cardiorespiratory parameters during the 1-min STS were comparable to those of the 6MWT (V'_{O_2}, V'_{CO_2}, RER, V'_E, V'_E, V_T, f_R and HR), whereas the end-exercise values for the 5STS were lower in comparison.

Figure 1 shows the course of V'_{O_2} for individual patients before, during and after exercise. Figure 2 shows the individual patient courses of S_{pO_2} and which of those patients experienced oxygen desaturation (decrease in S_{pO_2} ⩾4%) [33]. Based on end-exercise values, desaturation was detected after the 1-min STS test in seven out of 21 patients and after the 6MWT in 10 out of 15 patients. After visual inspection of S_{pO_2} profiles during the 1-min STS test, we saw that S_{pO_2} often continued to decline in the first minute after exercise (figure 2a). When using the lowest S_{pO_2} value in the first minute after exercise, desaturation was detected in four additional patients (patients 8, 12, 15 and 21) for the 1-min STS test (figure 2a). Comparisons of HR and Borg scale scores between cycle ergometry, 1-min STS test and 6MWT are given in table 6. End-exercise HRs were higher in the cycle ergometry than in the 1-min STS test and 6MWT (122.5 (95% CI 111.0–133.9) $beats \cdot min^{-1}$ *versus* 107.0 (95% CI 100.6–113.0) $beats \cdot min^{-1}$ and 108.0 (95% CI 98.2–118.0) $beats \cdot min^{-1}$). Patients reported marginally higher dyspnoea (0–10 scale) in the 1-min STS test than in cycle ergometry (4.6 (95% CI 3.1–6.1) *versus* 3.7 (95% CI 3.1–4.3)) and comparable leg fatigue (3.7 (95% CI 2.6–4.8) *versus* 3.8 (95% CI 3.2–4.5)).

TABLE 5 Physiological responses to the 1-min sit-to-stand (STS) test, five-repetition STS test and 6-min walk test (6MWT) at rest, during exercise and recovery

	Rest#			Exercise			Recovery#		
	1-min STS test	5STS test	6MWT	1-min STS test	5STS test	6MWT	1-min STS test	5STS test	6MWT
Subjects	21	21	15	21	21	15	20§	21	12f
Test score¶				18.9±5.4	10.1±4.4	376.1±89.4			
V'_{O_2} $mL \cdot kg^{-1} \cdot min^{-1}$	4.7 ±0.9	4.5±1.1	4.8±1.3	12.3±3.8	5.7±2.2	12.3±2.1	5.2±1.4	4.5±1.2	4.3±1.1
V'_{CO_2} $mL \cdot kg^{-1} \cdot min^{-1}$	4.1±0.8	3.7±0.9	4.0±1.3	10.5±3.1	4.7±2.1	10.6±2.5	5.4±1.5	3.8±1.1	4.0±1.0
RER	0.86±0.05	0.83±0.06	0.83±0.10	0.85±0.08	0.81±0.09	0.85±0.09	1.03±0.07	0.84±0.06	0.96±0.06
V'_E $L \cdot min^{-1}$	14.4±2.9	13.3±2.7	14.8±2.0	32.0±9.4	18.8±5.8	33.6±10.3	18.2±4.0	14.0±4.1	15.2±2.9
V_T L	0.85±0.27	0.91±0.36	0.92±0.29	1.23±0.39	0.73±0.39	1.27±0.32	1.09±0.37	0.85±0.30	1.04±0.36
f_R $breaths \cdot min^{-1}$	18.2±5.2	16.3±4.8	17.1±3.5	27.2±7.9	30.3±10.1	27.6±8.0	17.9±4.5	17.6±4.6	15.8±4.1
HR $beats \cdot min^{-1}$	87.8±8.0	88.2±10.3	83.5±10.2	107.0±10.9	97.1±9.8	107.3±14.8	88.7±8.8	87.0±9.2	88.7±10.7
S_{pO_2} %	92.8±7.7	92.5±3.0	92.7±2.8	90.1±3.4	91.7±2.5	85.8±6.3	94.4±2.0	92.6±2.5	94.0±3.0
Borg dyspnoea+	1.2±1.1	1.2±1.1	0.8±0.9				4·4±2.2	2.4±1.8	4.7±2.3
Borg leg fatigue+	1.2±1.3	1.0±1.0	0.7±0.8				3.7±1.7	2.1±1.7	2.8±1.8

Data are presented as n or mean±SD. V'_{O_2}: oxygen consumption; V'_{CO_2}: carbon dioxide output; RER: respiratory exchange ratio; V'_E: minute ventilation; V_T: tidal volume; f_R: respiratory frequency; HR: heart rate; S_{pO_2}: oxygen saturation. #: rest 3 min, recovery 5 min; ¶: 1-min STS test: repetitions, 5STS test: seconds, 6MWT: metres; +: Borg scales performed immediately pre- and post-test; §: one patient removed facemask immediately after test due to breathlessness; f: two patients removed facemask during recovery due to breathlessness; one patient was stopped due to S_{pO_2} of 70%.

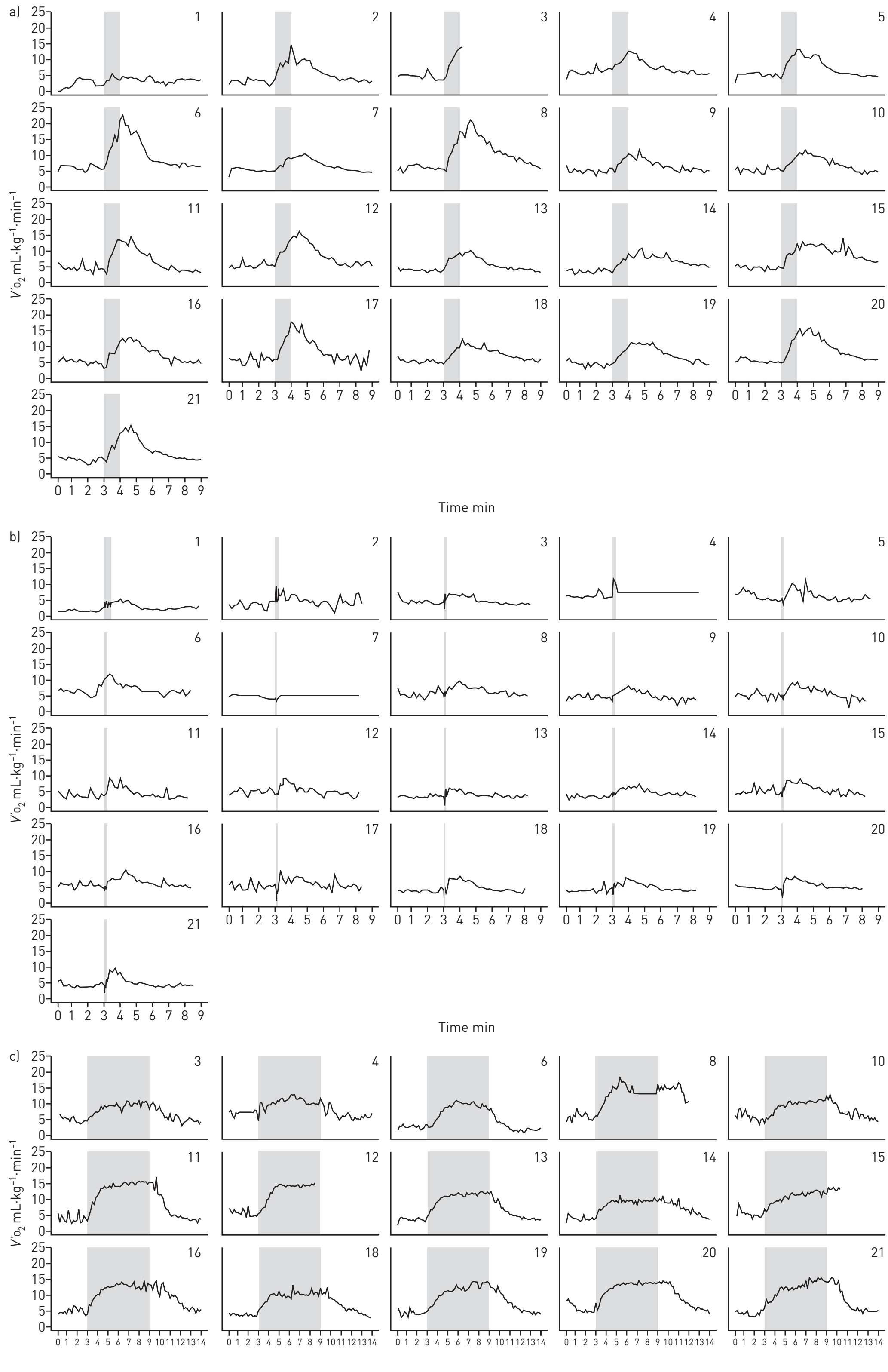

FIGURE 1 Oxygen consumption (V'_{O_2}) profiles for individual patients in each exercise test during rest, exercise and recovery. a) 1-min sit-to-stand test; b) five-repetition sit-to-stand test; c) 6-min walk test. Grey areas represent the duration of the exercise period. Data are plotted as 10-s averages apart from in b) where breath-by-breath data are plotted during exercise. Numbers in the upper right-hand corners represent individual patients, for comparison.

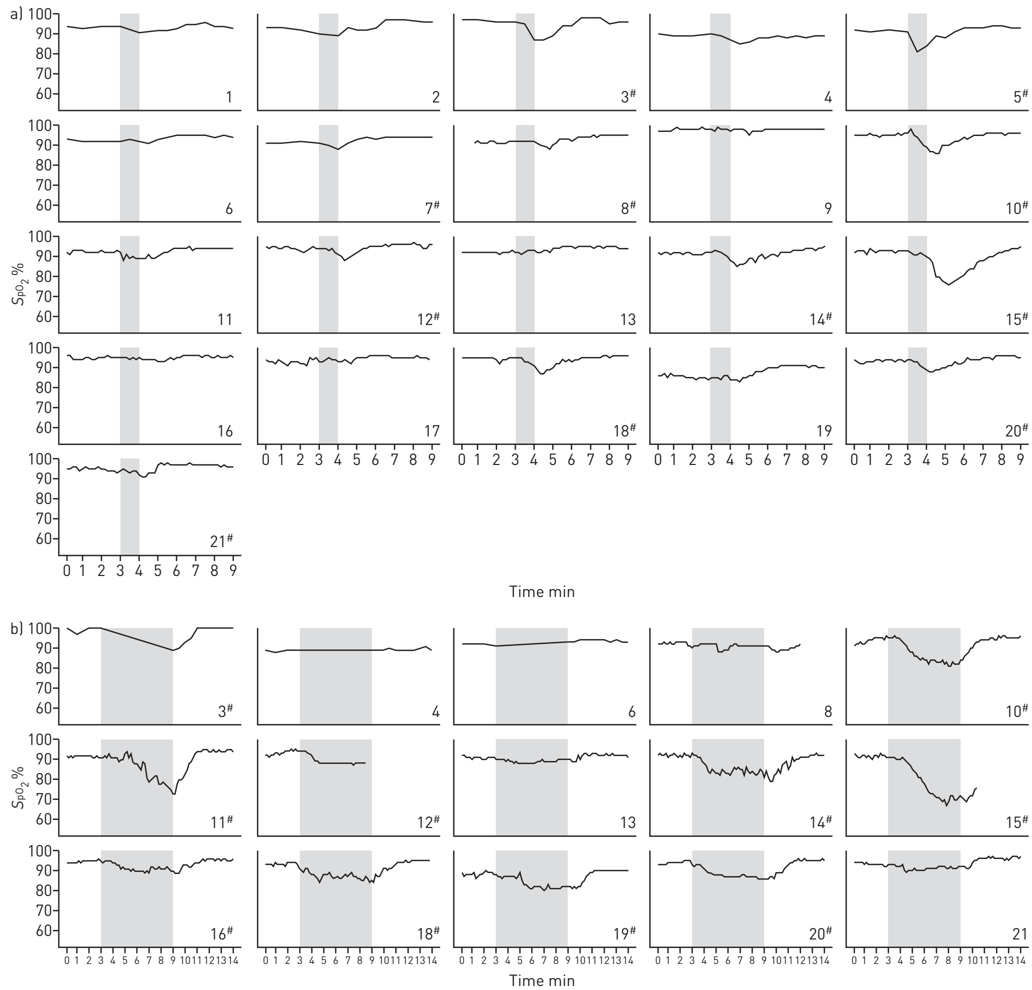

FIGURE 2 Arterial oxygen saturation measured by pulse oximetry (S_{pO_2}) profiles for individual patients in each exercise test during rest, exercise and recovery. a) 1-min sit-to-stand test and b) 6-min walk test. Grey areas represent the duration of the exercise period. Numbers in the lower right-hand corners represent individual patients, for comparison. Data are plotted as 10-s averages, apart from patients 3, 4 and 6 who have measurements each minute during rest and every 30 s during recovery. #: patient experienced oxygen desaturation with a decrease in $S_{pO_2} \geqslant 4\%$.

Discussion

We found that the 1-min STS test showed very little learning effect and excellent test–retest reliability in COPD patients. Strong correlations with the 6MWT suggest good cross-sectional construct validity. The 1-min STS test was responsive to two different pulmonary rehabilitation programmes, and the MID for

TABLE 6 Comparison of test scores, end-exercise heart rate, dyspnoea and leg fatigue during cycle ergometry, 1-min sit-to-stand (STS) test and 6-min walk test (6MWT) for patients who were assessed by cycle ergometry at baseline

	Cycle ergometry	1-min STS test	6MWT
Subjects	13	13	11
Test scores#	66.0±22.7	20.2±5.6	377.9±94.7
HR beats·min^{-1}	122.5±18.9	107.0±10.1	108.0±14.7
Borg dyspnoea	3.7±1.0	4.6±2.4	4.8±2.3
Borg leg fatigue	3.8±1.1	3.7±1.8	2.8±1.8

Data are presented as n or mean±SD. 1-min STS test: 1-min sit-to-stand test; 6MWT: 6-min walk test; HR: heart rate. #: cycle ergometry: W, 1-min STS test: repetitions, 6MWT: metres.

clinical practice was estimated as three repetitions. We also observed similar responses to the 1-min STS test and 6MWT in terms of end-exercise cardiorespiratory values.

This is the first study to thoroughly assess the measurement properties of the 1-min STS test in COPD patients. Our findings for cross-sectional validity of the 1-min STS test were in accordance with previous studies that also found moderate to strong correlations (r=0.47–0.75) with the 6MWT [5, 15] and with quadriceps strength (r=0.65) [5]. Many measures met our assumptions about strength of correlation, indicating good cross-sectional construct validity; however, the poor change score correlations with exercise capacity tests (<0.4) suggest that they may measure different aspects of exercise capacity that are not correlated over time. Our results showed that the 1-min STS test is responsive to pulmonary rehabilitation, in contrast with results seen previously [7] where only statistical significance testing was reported.

In the STAND-UP study we were able to assess the learning effect and test–retest reliability with repeated 1-min STS tests at each time point. We found an almost perfect ICC for test–retest reliability and a similar, albeit slightly lower, ICC for the learning effect. Based on the range of estimated MIDs and with more influence from the anchor-based estimates [29], we suggest an MID of three repetitions for COPD patients. Our results contrast with those seen in a population of cystic fibrosis patients, where a larger learning effect was seen (increase of eight repetitions) [34], and a higher MID of five repetitions was recommended. The cystic fibrosis patient population was younger (median (interquartile range (IQR)) age 29 (25.5–36.0) years) than our populations and performed considerably more repetitions (median (IQR) 56 (48.0–61.5)), which suggests that with higher exercise capacity, technique may have more impact on test score. In addition, COPD patients in the STAND-UP and RIMTCORE studies performed fewer repetitions compared to reference values from the general Swiss population for corresponding age categories based on the mean ages of the two studies (median (IQR) repetitions 45 (29–44) and 41 (33–48), respectively) [16].

Although the 1-min STS test and 6MWT involve different movements, they both elicited similar physiological responses. Quadriceps muscle strength is a known determinant of 6MWT performance [35, 36] and we observed comparable associations in our study for the 1-min STS test. This suggests that despite the differences in movements between the two tests, both heavily rely on quadriceps strength. While dyspnoea scores were comparable for the 1-min STS test and 6MWT, leg fatigue was rated 0.9 points higher for the 1-min STS test. We can only speculate that there is a greater perception of quadriceps muscle fatigue resulting from eccentric muscle contractions during the stand-to-sit phase of the 1-min STS test than the 6MWT [36]. In comparison to both the 1-min STS test and 6MWT, the 5STS did not elicit a strong cardiorespiratory response, most probably due to the very short test duration, suggesting that the usefulness of the 5STS for assessing exercise capacity may be limited.

We observed greater heterogeneity between individual patient V'_{O_2} responses to the 1-min STS test than the 5STS, but were unable to identify potential reasons for this based on individual baseline characteristics. In our study, we observed a decrease in S_{pO_2} during the 6MWT, similar to that seen in previous studies [37] (decrease of 7.2%); however, during the 1-min STS test we saw a decrease of 2.7% when calculated with end-exercise S_{pO_2}. This corresponds with previous studies that found a decrease in S_{pO_2} of 1–2% in the 1-min STS test [5, 7]. This could be due to either the shorter duration of the 1-min STS test or the 6MWT requiring more muscles than the 1-min STS test and therefore resulting in a greater metabolic demand and oxygen consumption. However, in the 1-min STS test we observed that S_{pO_2} often continued to decline in the first minute of recovery, and when using the lowest S_{pO_2} value in this minute, we detected desaturation during the 1-min STS test in all patients who desaturated in the 6MWT. We suggest measuring S_{pO_2} for 1 min after exercise if identification of desaturation is required. In the subsample of patients with maximal cycle ergometry data, we found that during the 1-min STS test patients achieved HR, dyspnoea and leg fatigue levels closer to those achieved in cycle ergometry than during the 6MWT. This shows the clinical relevance of the 1-min STS test, as the 6MWT is considered to be a good approximation of cycle ergometry in moderate to severe COPD [38].

One strength of our study is that we had data from two different COPD studies, one specifically designed to validate the 1-min STS test and one unrelated RCT, with different population characteristics and pulmonary rehabilitation programmes. This allows us to demonstrate the reproducibility of our results and that our findings can probably be applied to a wider COPD population. A further strength is that we were able to investigate all important measurement properties of the 1-min STS test in one study. Much consideration was put into designing the STAND-UP study to enable the assessment of all measurement properties while reducing as much bias and patient effort as possible. A limitation of our study is that there was a relatively large amount of missing data for the 6MWTs with cardiorespiratory gas analysis, although this was mainly due to technical problems and thus could be considered missing completely at random. An additional limitation is that we did not have maximal ergometry data for all patients and S_{pO_2} at maximal exercise was missing for most of those who did, meaning we could not correlate this with

1-min STS test and 6MWT end-exercise S_{pO_2}. Another limitation of the STAND-UP study is that we excluded patients who were unable to perform at least five repetitions. Previous experience showed us that these patients were often limited by musculoskeletal or neurological problems not directly related to exercise capacity, and we generally assumed that fewer than five repetitions in 1 min would not be enough to see a meaningful exercise performance. The threshold of five repetitions is arbitrary to some extent and limits the generalisability of our results to patients who fulfil these criteria (*i.e.* those without musculoskeletal or neurological limitations and those with the poorest exercise performance).

For use in clinical practice, we have provided a protocol for conducting the 1-min STS test to ensure consistency. Clinicians can easily integrate the 1-min STS test into practice to evaluate interventions and general state of health of their patients over time, as we have provided a means to determine a clinically relevant difference. Although suitable for most patients, the 1-min STS test may not be suitable for very poorly functioning patients who are unable to perform a minimum number of repetitions (we suggest five). Due to the small learning effect observed, we recommend that the 1-min STS test be performed twice if applicable and that the higher score of these should be used when possible, particularly in research. However, since the learning effect was negligible, we suggest that performing the test once would still give reliable results.

In conclusion, the 1-min STS test proves to be a promising alternative to traditional exercise capacity tests in COPD patients. It is reliable, valid and responsive and showed a comparable end-exercise physiological response to the 6MWT. We recommend an MID of three repetitions. The 1-min STS test is suitable for use in clinical practice and research settings when traditional tests are not practical.

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