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An original field evaluation test for chronic obstructive pulmonary disease population: the six-minute stepper test

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Purpose: The aim of this study was to evaluate a new field test, the six-minute stepper test (6-MST), by studying its reproducibility, sensitivity and validity.
Methods: After a familiarization test, 16 patients with chronic obstructive pulmonary disease (COPD) and 15 healthy subjects performed two six-minute stepper tests per day over three evaluation days. Ten of the 16 patients with COPD also performed a six-minute walking test (6-MWT) with an analysis of gas exchange to compare the metabolic requirements of the two tests. Dyspnoea Borg values were evaluated with Borg's CR-10 scale.
Results: The mean (SD) scores for the COPD group for the first and second six-minute stepper tests were 382.49 (106.01) and 412.45 (118.39) strokes/6 minutes, respectively. Crossed comparison between the first or the second six-minute stepper tests of each evaluation day revealed no significant difference, indicating the reproducibility of the test. The sensitivity was demonstrated by a significantly higher performance in the healthy group ($P<0.001$), demonstrating the ability of the test to detect two groups with different fitness levels. Finally, mean dyspnoea Borg values (SD) were significantly lower ($P<0.05$) during the six-minute stepper test than during 6-MWT (2.5 (1.5) versus 3.1 (1.2)).
Conclusions: This study demonstrated that the six-minute stepper test is a reproducible, sensitive, secure, well-tolerated and feasible test for patients with COPD. The reproducibility and sensitivity of the six-minute stepper test suggests that this test could be used in the evaluation of exercise tolerance in patients with COPD.

Introduction

The six-minute walking test (6-MWT) is a validated field test[1,2] that is frequently used to measure exercise tolerance or physical training effects in chronic obstructive pulmonary disease (COPD) studies.[3–6] Although the six-minute walking test has been adapted and validated successfully for

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many different populations,[7–14] it still presents some disadvantages. One of these is an environmental constraint: the corridor for the walking test needs to be at least 30 m long.[15,16] Shorter corridors force the patients to carry out more turnarounds, slowing them down and reducing walking distance. The performance of a six-minute walking test in an unsuitable environment cannot reflect the real exercise tolerance of patients with COPD.

Other field tests used to measure physical fitness in patients with COPD include the incremental shuttle walk test[17] or the endurance shuttle walk test.[18] These use a shorter distance (10 m) than the six-minute walking test. However, the incremental shuttle walk test is not a submaximal test and so cannot substitute for the six-minute walking test. For the endurance shuttle walk test, the walking speed is paced and the calculation of this walking speed is dependent on the maximal speed achieved during the test. In this way, this submaximal test presents two disadvantages (paced walking speed and requirement for an incremental shuttle walk test performance).

In order to avoid these limitations, a test performed on a stepper could be used to safely measure the physical capacity of patients with COPD and could be an alternative to the previously mentioned field tests. Dal Corso *et al.*[19] illustrate this possibility, proposing a step test of 6 minutes for patients with interstitial lung disease. Patients with COPD, however, are generally older than those with interstitial lung disease, which may make the use of a step test inadvisable as it could increase the risk of stumbling and the risk of falls by increasing imbalance. Moreover, articular problems frequently encountered with ageing mean that a stepper is probably a better apparatus than a step for patients with COPD. Finally, as the stepper is similar to the step, notably in terms of realized movement, and as the stepper is used in healthy seniors in fitness centres, we proposed a stepper test for patients with COPD.

This kind of test has already been proposed in an idiopathic pulmonary fibrosis population,[20] but to our knowledge there is no study which has focused on 6-minute stepper test validation in a COPD population.

We hypothesized that the six-minute stepper test could be a validated and useful tool to measure physical capacity for patients with COPD when the 6-minutes walking test cannot be practised in validated conditions. The aim of this study was to evaluate the reproducibility, sensitivity and validity of a six-minute stepper test in a COPD population in comparison with the six-minute walking test.

Methods

A parallel group design was used to compare subjects with and without a diagnosis of COPD. The project was approved by the hospital ethics review board (2007-A005256-48) and all participants provided written informed consent. Their anthropometric and spirometric values are presented in Table 1. Sixteen COPD outpatients coming to a medical centre to participate in a rehabilitation programme were recruited. Exercise tests on a stepper were performed during the first week of the rehabilitation programme. Fifteen healthy subjects were included in the study. This group was formed in order to study the sensitivity of the six-minute stepper test.

Subjects in both groups underwent spirometry tests (Medisoft, Dinant, Belgium). After the spirometry and a familiarization period on the stepper (V Fit S 726, Vivace Fitness, Durham, United Kingdom), all the patients and healthy subjects

Table 1 Anthropometric and spirometric values for COPD and healthy groups

Variable (units)	COPD ($n=16$)	Healthy ($n=15$)
Age (year)	61.4 (6.9)	29.0 (6.0)***
Height (cm)	172.5 (5.3)	175.2 (7.7)
Body mass (kg)	87.9 (21.5)	71.8 (15.0)*
BMI (kg/m^2)	29.4 (6.4)	23.2 (3.6)**
FEV_1 (L)	1.7 (0.6)	4.3 (0.9)***
FEV_1 (%)	53.5 (21.0)	106.1 (13.8)***
FCV (L)	3.0 (0.7)	5.6 (1.0) ***
FCV (%)	77.2 (16.8)	112.5 (15.3)***
FEV_1/FCV (%)	81.2 (21.2)	92.3 (7.1)

Values are mean (SD). *n*, number of subjects; BMI, body mass index; FEV_1, forced expiratory volume in 1 second; FCV, forced vital capacity (expressed in litres and in % of theoretical value).
*$P<0.05$; **$P<0.01$; ***$P<0.001$.

carried out six six-minute stepper tests. Finally, 10 of the 16 patients with COPD performed one six-minute walking test. All the tests were programmed over one week.

For the six-minute stepper test the instructions given were adapted from the instructions for the six-minute walking test given by the American Thoracic Society[16]:

The object of this test is to make the highest number of strokes you can during a six minute duration. Six minutes is a long time, so you will be exerting yourself. You will probably get out of breath or become exhausted. You are permitted to slow down, to stop, and to rest as necessary. You may lean against the wall while resting, but you have to resume exercise as soon as you are able. The correct movement is this one: you have to stretch the bent leg until the step has touched the stepper base. Then do the same movement with the other leg.

The testing was done in a small, isolated room in order to avoid any noise or auditory stimuli which can affect performance. The stepper was placed near a wall in order to permit the subject to put a hand on the wall if out of balance or exhausted. The starting position of the stepper was as follows: left or right step in upper position, the other step down, the arms along the body (Figure 1). For the upper position, the height of the step was fixed at 20 cm.[19] This height was verified before each test. Subjects could choose their preferred position (left or right foot down). After a two-minute rest period in the starting position the six-minute exercise test was performed.

During the exercise phase, only one instruction concerning the use of arms was given: never lean on the wall using the hands, unless imbalanced (Figure 1). In this case, subjects could use the wall in order to get their balance. The time since the beginning of the test was given to the subject after each minute for all the tests. This indication was the only one given to the subject during the test. No other form of encouragement was given. After each exercise minute, the number of strokes was reported on the subject's folder, a stroke corresponding to an entire cycle performed by the subject. An entire cycle was defined by return to the initial position. During all the tests, the

Figure 1 Pictures of a stepper and of positions adopted by subjects during the six-minute stepper test. The jacks refer to the hydraulic system which makes to the step go up and down. As mentioned in the apparatus manual by the manufacturer, the jacks may get hot after use.

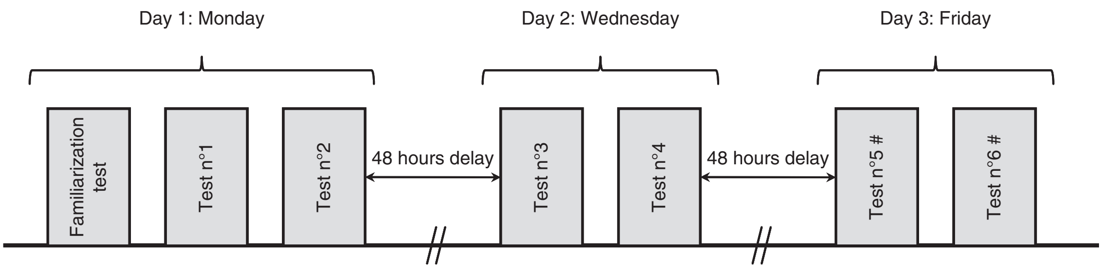

Figure 2 Study design for the seven six-minute stepper tests. Between each performed test, subjects rested for 10 minutes to return to resting heart rate values. #Tests performed with gas exchange measurement.

subjects could freely choose their own rate of stepping (i.e. cadence). At the end of exercise, the total number of strokes was noted and a two-minute passive recovery period was observed, for which the subject could step off the stepper. After this, a 10-minute resting phase was imposed to allow the subject's heart rate to return to resting values before a new trial.

In order to study six-minute stepper test reproducibility, each subject performed seven six-minute stepper tests:

- three on Monday
- two on Wednesday
- two on Friday.

Figure 2 shows the study design for these seven six-minute stepper tests. The first test on Monday is considered to be a familiarization period, which is required because no patient had previously performed an exercise on a stepper. After this, two six-minute stepper tests were performed each day. The first test on each day should be more difficult to perform than the second test as the hydraulic jacks of this type of apparatus are more flexible once they have warmed up (Figure 1).

When a new evaluation tool is proposed, it is necessary to verify the results on different levels of fitness in order to verify whether the test can discriminate populations with different levels of physical capacity. To do this, a healthy group was included in this study. This group also performed seven six-minute stepper tests. The tests were executed in the same order as with the patients with COPD and with the same instructions, time of exercise, recovery and measurements.

In order to study validity, 10 of the 16 patients with COPD performed a six-minute walking test following the American Thoracic Society recommendations.[16] This test was performed in a rectangular 70-m track. Arterial saturation, heart rate, dyspnoea and leg fatigue values were measured during all the tests. Arterial oxygen saturation (Sao_2) was measured with a portable oxymeter system (Oxymeter 3100, Nonin, Minnesota, USA). Heart rate values were recorded continuously with a heart rate monitor (Polar S810, Polar Electro Oy, Kempele, Finland). Dyspnoea and leg fatigue were evaluated with a modified CR-10 Borg Scale.[21] All those parameters were monitored every minute during each test. Gas exchanges were recorded breath-by-breath with a portable system (Cosmed K4b^2, Cosmed, Rome, Italy[22]) and were averaged every 20 seconds. The gas exchange measurement was only computed during the last two six-minute stepper tests and the six-minute walking test.

Data analysis

All the values were expressed as mean ± standard deviation (mean ± SD). For each parameter, data normality was tested with a Kolmogorov–Smirnov test.

For six-minute stepper test reproducibility and sensitivity, a two-way repeated measures analysis of variance ('test number' versus 'day' factors for reproducibility and 'group' versus 'test number' factors for sensitivity) was used to analyse physical performance over the six tests for the COPD group (reproducibility) and to compare mean values for patients with COPD and healthy subjects (sensitivity). When the ANOVA *F*-ratio was significant, the means were compared using pairwise multiple comparison procedures (Bonferroni post-hoc test).

To test the reproducibility in patients with COPD, the agreement between all the second tests was evaluated by the Bland–Altman procedure.[23]

For six-minute stepper test validity, several statistical tests were performed:

- A 'paired *t*-test' in order to compare physiological and psychological variables ($\dot{V}o_2$, ventilation, heart rate, dyspnoea and leg fatigue Borg scores). Mean $\dot{V}o_2$ of the last 3 minutes during the sixth six-minute stepper test and six-minute walking test were calculated. The same procedure was done for ventilation and heart rate data. Mean values of dyspnoea and leg fatigue Borg scores of the whole exercise were also estimated.
- A Bland–Altman procedure was performed between the mean $\dot{V}o_2$ of the last 3 minutes of the six-minute stepper test and six-minute walking test.
- Correlations between different parameters (number of strokes in 6 minutes versus walked distance in 6 minutes, oxygen uptake and heart rate) measured during the sixth six-minute stepper test and during the six-minute walking test were estimated with Pearson product moment correlation.

Significance level was set at the 0.05 level for all the performed tests.

Table 2 Comparison of the performance between COPD and healthy populations for each day

	COPD population	Healthy population
Six-minute stepper test (strokes/ 6 minutes)		
Familiarization test	368.4 (97.1)	553.4 (82.0)***
Test 1	373.7 (93.8)	620.6 (97.0)***
Test 2	404.9 (109.3)§	654.8 (107.9)***
Test 3	391.4 (104.2)	580.9 (75.8)***
Test 4	416.5 (115)§	656.5 (93.7)***
Test 5	382.4 (125.3)	655.7 (123.7)***
Test 6	416.2 (137.8)§	723.1 (137.2)***
Six-minute walking test (m)		
Test 1	444.1 (70.3)	

Values are expressed as means (SD).
***$P<0.001$ for the comparison between COPD and healthy groups performances.
§$P<0.05$: comparison between test 1 and test 2, between test 3 and test 4 and between test 5 and test 6 in patients with COPD.

Results

Anthropometric and spirometric values for the two groups are presented in Table 1.

Six-minute stepper test reproducibility

All patients with COPD performed all the six-minute stepper tests, except one subject who did not perform the last two tests because of a lack of motivation. The familiarization test, which was significantly lower than the other tests, was removed from the statistical analysis and graphs. The mean (SD) scores for the first and second tests were 382.49 (106.01) and 412.45 (118.39) strokes/6 minutes, respectively. As expected, because of the warming up of the hydraulic jacks in the stepper, a significant difference ($P<0.01$) appeared between all the first and second tests, with physical performance always significantly higher for the second test (Table 2). Statistical analysis revealed that there was a 'test number' effect without significant influence of the 'day' factor or significant interaction 'day and test number'. Thus, the mean difference of stepper scores between the two tests performed on the same day (Δ Perf) was calculated. There was no significant difference between the three days (31.2 (44.5) for day 1; 25.1 (25.0) for day 2 and 33.8 (35.5) for day 3, expressed in number of strokes/6 minutes). Moreover, between all the first or between all the second tests, there was no significant difference for the rate of stepping and for the performance. This absence of difference was confirmed by Bland–Altman plot (Figure 3). In this figure, the mean bias ± 95% confidence interval (95% CI) of the stepper performance were 11.6 (105.6) (Figure 3a), −0.3 (136.4) (Figure 3b) and 11,3 (143.3) number of strokes/6 minutes (Figure 3c).

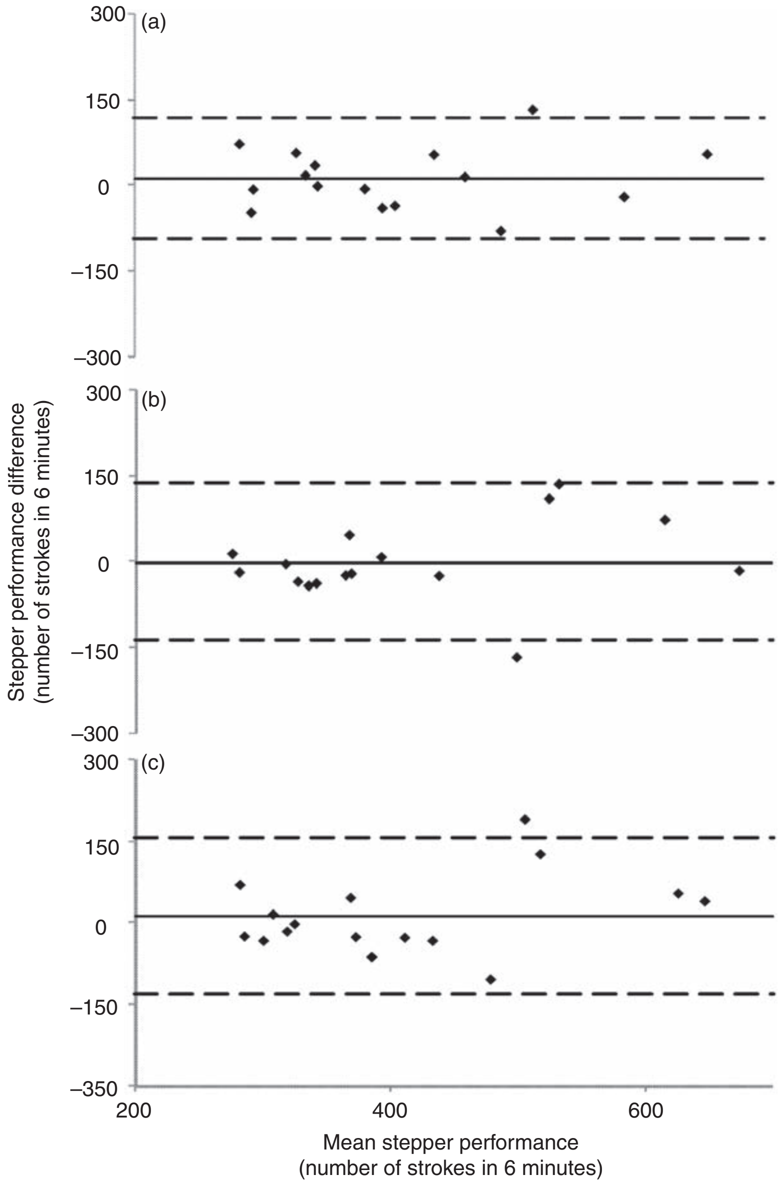

Figure 3 Bland–Altman plot of the differences between second tests in mean stepper score in the COPD population. (a) First day and second day. (b) Second day and third day. (c) First day and third day. Solid line is mean; dashed lines is ±1.96 SD.

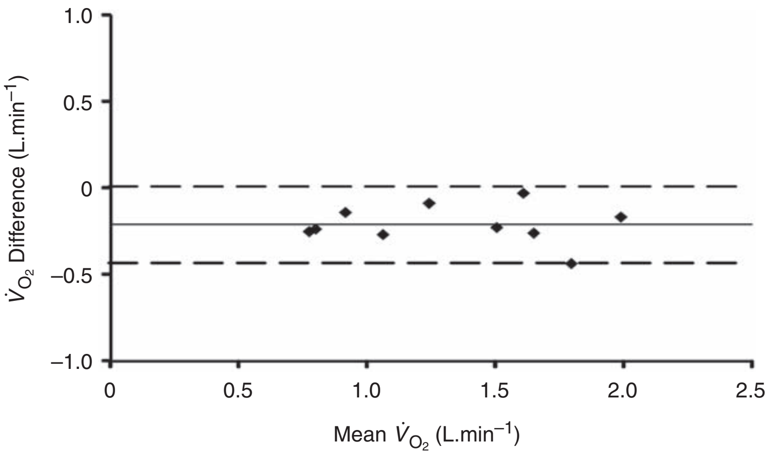

Figure 4 Bland–Altman plot of the between-test differences in mean oxygen uptake values measured during six-minute stepper test no. 6 and the six-minute walking test. Solid line is mean; dashed lines is ±1.96 SD. The mean oxygen uptake values correspond to the mean values of the last 3 minutes of each exercise.

Six-minute stepping test sensitivity

The healthy subjects had significantly higher scores than patients with COPD ($P<0.001$; Table 2). Mean six-minute stepper test scores (SD) for the healthy and the COPD group were 635.0 (83.8) and 395.5 (104.0) strokes/6 minutes, respectively.

Validity and cardiopulmonary comparisons

Mean $\dot{V}o_2$ (SD) was significantly lower ($P<0.01$) by 15% for the six-minute stepper test than for the six-minute walking test (14.0 (3.5) and 16.6 (3.3) mL/min per kg, respectively or 1.2 (0.4) and 1.4 (0.4) L/min). The mean bias (CI) of the $\dot{V}o_2$ difference between the second six-minute stepper test and the six-minute walking test was −0.2 (0.2) L/min (Figure 4).

For the last 3 minutes of exercise, there was no significant difference for mean heart rate (SD) between six-minute stepper test and six-minute walking test (respectively 118.2 (18.7) and 120.8 (12.6) bpm). Similarly, there was no significant difference in mean ventilation (SD) between the two field tests (respectively 38.8 (12.6) and 41.4 (13.2) L/min). Mean dyspnoea perception Borg score (SD) was significantly lower ($P<0.05$) for the six-minute stepper test (2.5 (1.5)) than for the six-minute walking test (3.1 (1.2)). There was no significant difference in mean leg fatigue perception Borg score (3.4 (2.5) for the six-minute stepper test and 2.8 (2.1) for six-minute walking test).

No correlation was found between six-minute stepper test performance and six-minute walking test distance ($r=0.42$), but significant correlations were found for cardiorespiratory parameters between both field tests ($r^2=0.97$; $P<0.001$ for oxygen uptake and $r^2=0.89$; $P<0.01$ for heart rate; Figure 5).

Discussion

The present study showed that the six-minute stepper test can be a reproducible evaluation tool, well tolerated and a secure test for patients with COPD. It is also sensitive, which means it can be used in different levels of physical fitness. Therefore, the six-minute stepper test is a portable and inexpensive method to assess the current level of exercise tolerance in patients with COPD.

A familiarization period was performed by all the subjects. This period seems to be required since stepper exercise is not familiar for many people. The results of the familiarization test have not been included because the statistical analysis

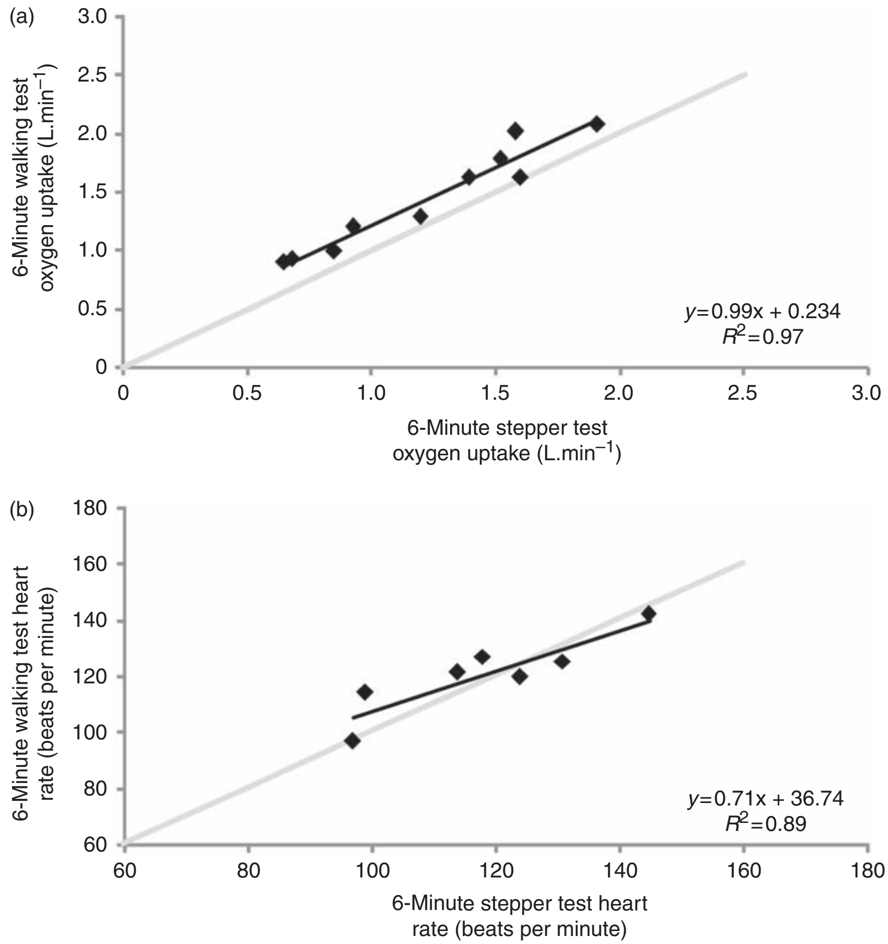

Figure 5 Correlations between six-minute stepper test and six-minute walking test in cardiorespiratory parameters (oxygen uptake and heart rate). Grey line represents the line of identity. The two correlations were significant ($P<0.001$ for oxygen uptake correlation and $P<0.01$ for heart rate correlation).

demonstrated that the scores were significantly lower than those for the other tests ($P<0.05$). This result was expected as a familiarization period is also necessary for the six-minute walking test when this walking test is used for the first time.[24,25]

In order to guarantee six-minute stepper test reproducibility, we proposed a standardized protocol based on the six-minute walking test protocol and controlled the encouragements because they influence performance, as reported in studies on the six-minute walking test.[9,26] Second, several trials were performed by all the subjects during a short period (six trials over one week) as traditionally encountered in the literature.[2,8,24,27] Apart from the study by Dal Corso *et al.*,[19] on interstitial lung disease, it was the first study to focus on the reproducibility of exercise tolerance on a stepper in patients with COPD. Balfour-Lynn *et al.*,[28] in a study on patients with cystic fibrosis, imposed a rate of stepping (30 steps/min). Although the reproducibility was good, with this kind of protocol the alteration of exercise tolerance cannot be easily evaluated. Moreover, the exercises performed in these two studies[19,28] were on a step, which is not advisable with an elderly population as patients with COPD often have articular disorders or may stumble against the step, inducing falls.

Statistical analysis demonstrated that for each evaluation day, there was a significant variation in stepper scores between the first and the second test. These results were expected as this kind of apparatus contains hydraulic jacks that become more flexible with use as they warm up. The stepper effect seems to be confirmed as there was no significant difference between all the first or all the second tests of each day, as well as for the cadence. We can also hypothesize that the 'learning' effect could explain the performance increase between the first and the second test, as reported for six-minute walking test.

Many studies focusing on walking exercises, especially the six-minute walking test, report the need for a prior practice test in order to limit the skill effect.[2,5,8,9,27,29,30] This recommendation has also been used by Rammaert *et al.* with stepper tests.[20] But when the patients are familiarized with the stepper test, as encountered in rehabilitation follow-up for example, only one six-minute stepper test could be performed as there was no significant difference between all the first or all the second tests. This specific methodological point is also noted for the six-minute walking test.[16]

When a new evaluation tool is proposed it is necessary to ensure that it is reproducible and sensitive. The reproducibility was demonstrated above. To measure the sensitivity of the six-minute stepper test a healthy adult group was included. The results demonstrated that the performances of the healthy group were significantly higher than those of the patients with COPD. Thus, the six-minute stepper test can be introduced into the evaluation of patients with COPD as it can detect populations with different fitness levels. This result is interesting as a rehabilitation programme traditionally improves physical capacity in a COPD population.[31] Thus, we could hypothesize that the stepper could measure the alteration of fitness level as this test is able to measure higher performance. Rammaert *et al.*[20] used a six-minute stepper test in idiopathic pulmonary fibrosis and they measured a significant improvement in scores after an eight-week rehabilitation programme. But they did not focus specifically on the reproducibility and the sensitivity of the test.

The six-minute stepper test's validity was also assessed in our study. Assessments of cardiorespiratory responses between the stepper and walking tests showed that mean oxygen uptake was significantly higher by 15% for the six-minute walking test. Some studies have estimated metabolic requirement during the six-minute walking test[5,32] and have reported a mean $\dot{V}O_2$ of 1.40 ± 0.29 L/min,[5] which is similar to our results. On the other hand, there are no data available in the literature about oxygen uptake evaluation during stepper exercise. The difference observed between mean $\dot{V}O_2$ for the six-minute stepper test and six-minute walking test could be explained by various factors. First, the activated muscle mass could be smaller for stepper activity in comparison to walking activity because the ascending leg is assisted by the descending leg and the gravitational effect. This assistance of the descending leg and the gravitational effect could induce more passive phases in comparison with walking activity, which is mainly composed of active phases. Second, movement of the upper limbs could explain the difference between mean $\dot{V}O_2$. During stepper use, the upper limbs move very little (see Methods) whereas walking induces the movement of the upper limbs. These mechanical differences could be responsible for the higher metabolic requirement during the six-minute walking test and explain the higher mean $\dot{V}O_2$.

Finally, the lack of correlation between the scores (number of strokes in 6 minutes versus walked distance in 6 minutes) of the two field tests was highlighted. This result indicated that it is not possible to predict the scores of one test with those of the other. This could be expected as the motor pattern is not the same between walking and doing stepper. Nevertheless, the six-minute stepper test evaluates the same cardiorespiratory dimension as the six-minute walking test: endurance capacity, which demonstrates the validity of the six-minute stepper test. These results were demonstrated by the significant correlations found for oxygen uptake and heart rate measured during the two field tests.

Our results showed that dyspnoea perception score was significantly higher during the six-minute walking test than during the six-minute stepper test, whereas there was no significant difference in leg fatigue perception score.

The higher perception score observed for the six-minute walking test could be a result of the proposed physical activity. Several studies have reported higher Borg dyspnoea scores for walking tests than cyclo-ergometer tests.[32,33] One of the advanced hypothesis is that arms may be a potential source of increased afferent input to the respiratory centres.[34] As described above, the upper limbs were inactive during the six-minute stepper test in contrast to the six-minute walking test in our study. So the inactivity of the arms during stepper tests could play a role in the observed difference in dyspnoea perception score, as observed for cyclo-ergometer tests in comparison with treadmill.

Some limitations of our study should be considered. This study was based on a cross-sectional design and brings limited information on six-minute stepper test sensitivity, including for example the six-minute stepper test performance before and after a rehabilitation programme. In idiopathic pulmonary fibrosis, Rammaert *et al.* have highlighted a significant improvement in performance after a home-based rehabilitation programme.[20] Further studies are required in order to investigate the sensitivity of this new field test in more detail, especially in COPD population. A second limitation concerns the age difference between the groups included in this study. The healthy young population was included to demonstrate the absence of apparatus limitation in obtaining a better performance. A comparison between the six-minute stepper test scores of a COPD group and the scores of an age-matched healthy group would make possible to avoid an age effect and to highlight the effect of COPD on the performance realized on stepper. Finally, it would be interesting to obtain values for several stages of the disease (GOLD stages), in order to estimate lower and higher limits of stepper performance.

In summary, the six-minute stepper test can be proposed as a new endurance evaluation tool in COPD as it is reproducible, secure, transportable and inexpensive. This new submaximal field test can evaluate exercise tolerance in some patients showing a different level of exercise capacity. Finally, the absence of drop-outs demonstrates the feasibility of the six-minute stepper test with this specific population.

Clinical messages

- The six-minute stepper test is a new field test that is feasible to use in medical surgery, in hospital or at home (transportable, low space required, low cost).
- The six-minute stepper test is a submaximal test allowing the assessment of the endurance capacity, like the six-minute walking test.
- The six-minute stepper test is a reproducible submaximal field test for patients with mild to moderate COPD.

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Conflicts of interest

No financial or other potential conflicts of interests exist for all the authors.

Author contributions

All authors have read and agreed to the statement. BB contributed to writing the paper, initiating the study, designing the study, monitoring progress and deciding on the analytic strategy. CF contributed to writing the paper, initiating the study, designing the study, monitoring progress and deciding on the analytic strategy. SS contributed to initiating the study and monitoring progress. FB contributed to initiating the study, designing it and monitoring progress. JMG contributed to writing the paper, initiating the study, designing the study, monitoring progress and deciding on the analytic strategy.

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