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A M E R I C A N C O L L E G E O F
 C H E S T
P H Y S I C I A N S

Metabolic and Ventilatory Parameters of Four Activities of Daily Living Accomplished With Arms in COPD Patients*

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Study objective: The upper limbs are involved in the activities of daily living (ADLs). Normal subjects usually perform such activities without noticing the energy cost, but patients with COPD report tiredness when performing them. This study was designed to assess the metabolic and ventilatory demands in patients with COPD during the performance of four ADLs involving the upper limbs.

Design: The patients were tested on two different days. Oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$), minute ventilation ($\dot{V}E$), and heart rate were measured while performing four ADLs for 5 min each: sweeping, erasing a blackboard, lifting pots, and replacing lamps.

Participants: Ten normal, young, male subjects (mean age, 27.9 years) were selected for testing the reproducibility of the methods, and 9 male patients with COPD (FEV₁, 32.5%; mean age, 58.9 years) entered the study.

Measurements and results: The tests were reproducible for both groups. Patients with COPD presented a significant increase ($p < 0.05$) in $\dot{V}O_2$ (mean, 50.2% of maximum $\dot{V}O_2$) and in $\dot{V}E$ (mean, 55.7% of maximum voluntary ventilation [MVV]) in relation to initial resting conditions for all four activities.

Conclusions: We conclude that when performing these four activities, patients with moderate-to-severe COPD present a high $\dot{V}O_2$, which may explain the tiredness reported by them during simple activities involving the upper limbs; the high $\dot{V}E$ /MVV may be associated to dyspnea.

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Key words: activities of daily living; COPD; dyspnea; fatigue; minute ventilation

Abbreviations: ADL = activity of daily living; HR = heart rate; HRmax = maximum heart rate; MVV = maximum voluntary ventilation; UNIFESP = Federal University of São Paulo; $\dot{V}CO_2$ = carbon dioxide output; $\dot{V}E$ = minute ventilation; $\dot{V}O_2$ = oxygen uptake; $\dot{V}O_{2max}$ = maximum oxygen uptake

Patients with COPD report fatigue and dyspnea when performing activities of daily living (ADLs) that require the use of the upper limbs. In 1973, Tangri and Wolf¹ observed that patients with COPD acquired an irregular, superficial, and rapid respiratory pattern when performing activities requiring the upper limbs, such as tying a pair of shoes and

combing hair. In 1986, Celli et al² studied the ventilatory and metabolic response during unsupported arms exercise in patients with COPD and showed this exercise led to thoracoabdominal dys-synchrony and dyspnea within a shorter period of time and a smaller oxygen uptake ($\dot{V}O_2$) compared to the demand for leg exercise.

Couser et al³ showed that the simple elevation of the arms of normal individuals results in a significant increase in $\dot{V}O_2$ (16%) and in pulmonary ventilation (24%), associated to an increase in the final gastric inspiratory and transdiaphragmatic pressure, suggesting that arm elevation disturbs the mechanics of the chest and abdominal compartments. Martin et al⁴ observed that maximum exercise of the upper limbs represents a submaximal cardiopulmonary stress compared to peak leg exercise on a cycle ergometer, with higher carbon dioxide production ($\dot{V}CO_2$), a higher respiratory coefficient (R), and a

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higher minute ventilation (\dot{V}_E), suggesting that upper-limb exercise reaches the anaerobic threshold earlier than leg exercise with comparable workloads and $\dot{V}O_2$. Differences in the proprioceptive reflexes of the limbs or the use of accessory respiratory muscles during upper-limb exercise as compared to the leg exercises may explain the difference in the respiratory pattern.

Although there are some studies of patients with COPD who have had $\dot{V}O_2$, $\dot{V}CO_2$, and \dot{V}_E measured during upper-limb exercise,^{5,6} no study has ever reported in the literature the measurements of patients with COPD while performing ADLs. On this basis, the objective of the present study was to assess the metabolic and ventilatory demand of patients with COPD while performing the four ADLs (sweeping the floor, erasing a blackboard, lifting pots, and changing bulbs), which require the upper limbs in distinct positions, with and without support, and compare the results to the estimated maximum $\dot{V}O_2$ ($\dot{V}O_{2max}$) in order to determine the actual magnitude of the increase in the metabolic and ventilatory demand during ADLs in patients with COPD.

MATERIALS AND METHODS

Nine male patients with COPD were selected according to the criteria outlined by the American Thoracic Society⁷ from a group who were undergoing initial examinations in order to enter the pulmonary rehabilitation program at the Center of Pulmonary Rehabilitation of the Federal University of São Paulo (UNIFESP). Ten normal male subjects recruited from students enrolled in various postgraduate courses at UNIFESP were used to test the reproducibility of the equipment. The UNIFESP ethics committee approved the protocol, and all subjects signed a consent form after receiving explanations about the purpose of the investigation. Table 1 lists the characteristics of the sample studied.

The inclusion criteria for COPD patients were as follows: (1) $FEV_1 \leq 1.2$ L, with these patients being considered to have moderate-to-severe COPD (American Thoracic Society, 1995); (2) clinically stable condition, with no pulmonary infections during the previous 4 weeks and with no other associated disease (heart, rheumatic or orthopedic disease); and (3) no engagement in any fitness program (sedentary).

Table 1—Characteristics for Nine Patients With COPD

Variables	Mean (SEM)
Age, yr	58.9 (3.43)
Weight, kg	66.1 (3.4)
Height, cm	173.4 (2.2)
Body mass index	22.0 (0.93)
FVC, L	2.8 (0.19)
FVC, % predicted	75.4 (6.5)
FEV_1 , L	1.0 (0.04)
FEV_1 , % predicted	32.5 (1.8)
FEV_1/FVC , %	37.1 (2.54)

Protocol

The patients were continuously evaluated with respect to $\dot{V}O_2$, $\dot{V}CO_2$, \dot{V}_E , heart rate (HR), and dyspnea index according to the Borg scale both at rest and during the execution of the following four ADLs. (1) Sweeping the floor using a broom with nylon bristles for 5 min on a previously determined rubber surface. The movements of the individuals during this activity were constricted to a small area due to the limited extension of the tube that connected the metabolic system to the face mask of the individual for the collection of information about the metabolic and ventilatory variables. (2) Erasing a blackboard for 5 min with the blackboard placed in front of the individual. The subject started this activity with the dominant upper limb semi-flexed at the elbow but was allowed to switch arms if he became fatigued. (3) Lifting pots weighing 0.5, 1.0, 2.0, 3.0, 4.0, and 5.0 kg with both arms simultaneously extended in order to pick up the pots that were at waist level, and then lift them above the head and put them down on a surface at that level. The arms were then lowered without a weight, and the individual performed the opposite effort, picking up the pot above his head and putting it down at waist level. The exercise was started by lifting the lightest pot and continued with progressively heavier pots until the series was completed. The series was repeated as many times as necessary to complete 5 min, and the number of series completed was not taken into consideration. (4) Screwing in and out a bulb from four sockets placed at the height of the eyes, starting with the dominant arm semi-flexed at the elbow. However, switching arms during this activity was permitted depending on fatigue. This activity was performed over a period of 5 min, and number of bulb changes was not taken into account. Before starting a new activity, the individual was allowed to return to basal HR levels and Borg score for dyspnea. Both patients with COPD and normal subjects underwent two tests separated by a maximum period of 2 weeks, as long as their clinical conditions remained unchanged, in order to study the reproducibility of the data collected.

$\dot{V}O_2$ and $\dot{V}CO_2$ Measurements

The respiratory and metabolic variables were measured with the Vista XT Metabolic System computer program (Vista; Ventura, CA). This system operates with a turbine-like flowmeter lined with software and connected to the expiratory outlet of the Hans-Rudolph R2600 valve (Hans-Rudolph; Kansas City, MO). Expired air was continuously sampled from a mixing chamber with rapid-response oxygen and carbon dioxide analyzers. The flow signals and the percentage of expired gases were processed after analog-to-digital conversion in order to calculate the respiratory and metabolic variables at 20-s intervals (Vista Turbofit). A complete calibration routine included in the software itself ensured the correctness of the calibration procedures and was performed before each experiment.

$\dot{V}O_2$: $\dot{V}O_2$ was measured as standard temperature and pressure, dry, in liters per minute and/or milliliter per kilograms per minute, and compared the percentage of predicted $\dot{V}O_{2max}$ values for patients with COPD. We used the estimate of $\dot{V}O_{2max}$ with the equation obtained in previous experiments in the same laboratory exercise: $\dot{V}O_{2max} = 0.55 + (0.43 \times FEV_1)$, where FEV_1 is very similar to the one developed by Carter et al.⁸

\dot{V}_E : \dot{V}_E was measured with a turbine flowmeter linearized with software and expressed in liters per minute. To compare obtained \dot{V}_E to maximum voluntary ventilation (MVV), we estimated MVV values as $FEV_1 \times 35$.^{9,10}

HR: HR during exercise was analyzed with a pulse meter (Vantage XL; Polar; Kempele, Finland) with recordings at 5-s intervals. After the tests, the HR curves were stored in a

computer. Maximum heart rate (HRmax) was evaluated in absolute terms (beats per minute) and as percentage of maximum predicted HR: $HR_{max} = 210 - (0.65 \times \text{age})$.¹¹

Statistical Analysis

Since the data obtained did not show normal distribution, we used nonparametric statistical methods, but the results are reported as means \pm SEM since this is the more usual presentation for the interpretation and understanding of the results. For comparative analysis of reproducibility, we applied the Wilcoxon test to the data for $\dot{V}O_2$, $\dot{V}CO_2$, and $\dot{V}E$ obtained in each ADL performed on the first and second days of the test. Friedman analysis of variance was used to compare the four ADLs and the initial rest. The level of significance was set at $p < 0.05$.

RESULTS

Reproducibility

One of our concerns in this study was the reproducibility of the metabolic and ventilatory data obtained during the two tests. For this reason, patients with COPD and normal subjects were submitted to two tests on different days as long as the same clinical conditions were maintained. When the Wilcoxon test for paired samples was applied to compare the activities performed on the first and the second day of the test, we noted that the probability of the data being equal was very high both for patients with COPD and for normal individuals ($p > 0.05$; Table 2).

Metabolic and Ventilatory Cost

Patients with COPD presented a significant increase ($p < 0.05$) in $\dot{V}O_2$ and in $\dot{V}E$ in relation to initial resting conditions for all four ADLs (sweeping, lifting pots, changing bulbs, and erasing a blackboard). Sweeping, lifting pots, and changing bulbs caused a significantly higher $\dot{V}CO_2$ in patients with COPD compared to initial resting conditions (Table 3).

The $\dot{V}O_2$ measured during the four ADLs divided by $\dot{V}O_{2max}$ predicted for each patient showed a difference in terms of percentage of the median;

these data presented a higher predicted resting $\dot{V}O_{2max}$ (median, 39%). The increase in $\dot{V}O_2$ was significant reaching as much as 61% of predicted $\dot{V}O_{2max}$ for the pot-lifting activity (Table 3). The relationship between $\dot{V}E$ measured during the four ADLs and MVV predicted in the spirometry performed on the day of the test showed a difference in percentage of the median, presented a significant increase in $\dot{V}E$ and using as much as 62% of their MVV (Table 3). The HRmax reached in each ADL divided by HRmax predicted for each patient showed an increase in terms of percentage of the median for all activities analyzed ($p < 0.05$; Table 3).

DISCUSSION

As far as we know, this is the first study to determine the actual magnitude of the increase in the metabolic and ventilatory demand during ADLs in patients with COPD. The metabolic and ventilatory variables measured in patients with COPD during the ADLs were significantly increased, reaching as much as 55% of the estimated $\dot{V}O_{2max}$ and 62.7% of MVV. These values are very high and explain the tiredness, and at times exhaustion, when these patients perform simple daily activities with their upper limbs. Performing these activities increased the demand for oxygen and lead to the use of a large part of the ventilatory reserve of these patients and to increased perception of dyspnea, with a consequent limitation in ADLs.

On the basis of the studies by Ries et al¹² and Bauldoff et al,¹³ and on our own clinical experience, we selected ADLs that required varying amplitude of movements of the upper extremity, with different degrees of involvement of the muscles of the thorax. The high $\dot{V}O_2$ reached by our patients indicated that they worked at a high energetic cost. We cannot relate this $\dot{V}O_2$ to the anaerobic threshold for upper muscles since we did not measure the anaerobic threshold and there is no literature concerning this aspect. Maximal exercises with the arms usually

Table 2—Probabilities of No Difference by Wilcoxon Test To Show the Reproducibility of the Metabolic and Ventilatory Data Obtained During the Two Tests in Normal Subjects and in Patients With COPD

Relationship Between Activity Tests, Test 1 vs Test 2	COPD Probabilities			Normal Subject Probabilities		
	$\dot{V}O_2$	$\dot{V}CO_2$	$\dot{V}E$	$\dot{V}O_2$	$\dot{V}CO_2$	$\dot{V}E$
Initial rest	0.374	0.213	0.859	0.799	0.507	0.507
Sweeping the floor	0.678	0.767	0.678	0.444	0.284	0.721
Erasing a blackboard	0.441	0.678	0.594	0.799	0.721	0.202
Lifting pots	0.594	0.317	0.594	0.169	0.333	0.037*
Screw in and out a light bulb	0.213	0.515	0.767	0.386	0.575	0.169
Final rest	0.138	0.374	0.767	0.169	0.386	0.169

* $p < 0.05$ difference statistically significant between tests.

Table 3— $\dot{V}O_2$, $\dot{V}CO_2$, and $\dot{V}E$, as Well as the Percentages of $\dot{V}O_2/\dot{V}O_{2max}$, $\dot{V}E/MVV$, and HR/HR_{max} in Four ADLs in Nine Patients With COPD

ADLs	$\dot{V}O_2$, mL/kg/min*		$\dot{V}CO_2$, mL/kg/min*		$\dot{V}E$, L/min*		$\dot{V}O_2/\dot{V}O_{2max}$, %†	$\dot{V}E/MVV$, %†	HR/HR_{max} , %†	O_2 Pulse, mL/min†
Baseline	4.8 (1.5)	5.8	4.3 (1.3)	4.8	14.8 (4.8)	15.3	39	38	55	3.56
Sweeping the floor	7.8 (2.7‡)	8.7	6.3 (1.9‡)	7.2	20.7 (3.3‡)	21.2	52‡	54‡	62‡	5.14
Erasing a blackboard	7.3 (2.2‡)	8.0	5.3 (1.6)	6.1	20.4 (6.5‡)	21.7	45‡	51‡	63‡	4.72
Lifting pots	8.7 (2.1‡)	10.3	6.7 (2.1‡)	8.4	23.0 (7.7‡)	25.1	61‡	62‡	70‡	5.14
Replacing lamps	6.8 (2.4‡)	7.5	5.3 (2.0‡)	4.5	20.2 (6.7‡)	19.6	43‡	56‡	66‡	4.07

*Data presented as mean, (SEM), and median.

†Data presented as median.

‡p < 0.05 difference significantly different to baseline.

reach a $\dot{V}O_2$ equivalent to 50% of the $\dot{V}O_{2max}$ reached during a maximum treadmill exercise (observations not published). The anaerobic threshold of patients with COPD during a maximum leg exercise varies according to the severity of the disease, being higher the more obstructed the patient is, reaching values as high as 85 to 90% of the $\dot{V}O_{2max}$.¹⁴

The sweeping activity was chosen because it keeps the arms lowered, not requiring an ample movement of the shoulder or an intense involvement of the upper musculature of the thorax for the maintenance of this position. Erasing a blackboard mimics daily activities such as cleaning windows and painting walls, among others, keeping the arms elevated and unsupported; the fact that it is performed with constant movements requires a marked involvement of the upper musculature of the thorax. Lifting pots of different weights is an

extremely dynamic activity involving intense amplitude of arm movements, especially by the shoulders. Changing bulbs, although not representing a routine activity, was selected because it involves complex and fine hand movements, in addition to requiring elevated arms throughout the period of its execution that should lead to an intense usage of the upper musculature of the thorax.

Some studies have demonstrated that the activities that maintain the arms elevated and unsupported produce a sensation of dyspnea and thoracoabdominal dyssynchrony,¹⁵ an increase in $\dot{V}O_2$ and $\dot{V}E$,^{3,16} and an increase in $\dot{V}CO_2$, respiratory rate, and HR.⁵ Our results show that the four studied activities produced a significant increase in $\dot{V}O_2$ (Fig 1), $\dot{V}CO_2$, $\dot{V}E$ (Fig 2), and HR (Fig 3) [p < 0.05], supporting the aforementioned literature.

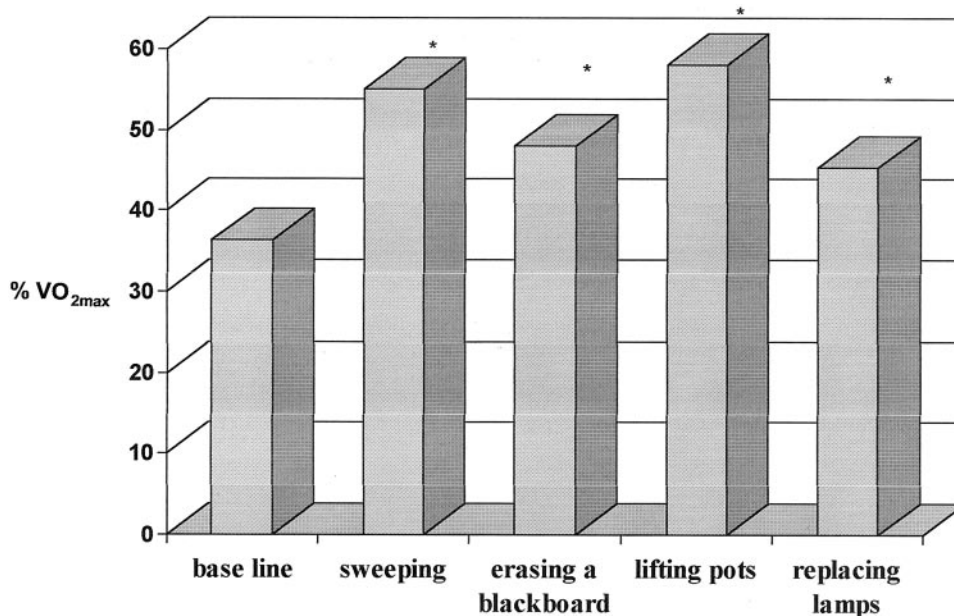


FIGURE 1. Comparison of the means of $\dot{V}O_2$ in percentage of $\dot{V}O_{2max}$ obtained during the performance of four ADLs in nine patients with COPD (p < 0.05). * = p < 0.05 difference significantly different from baseline.

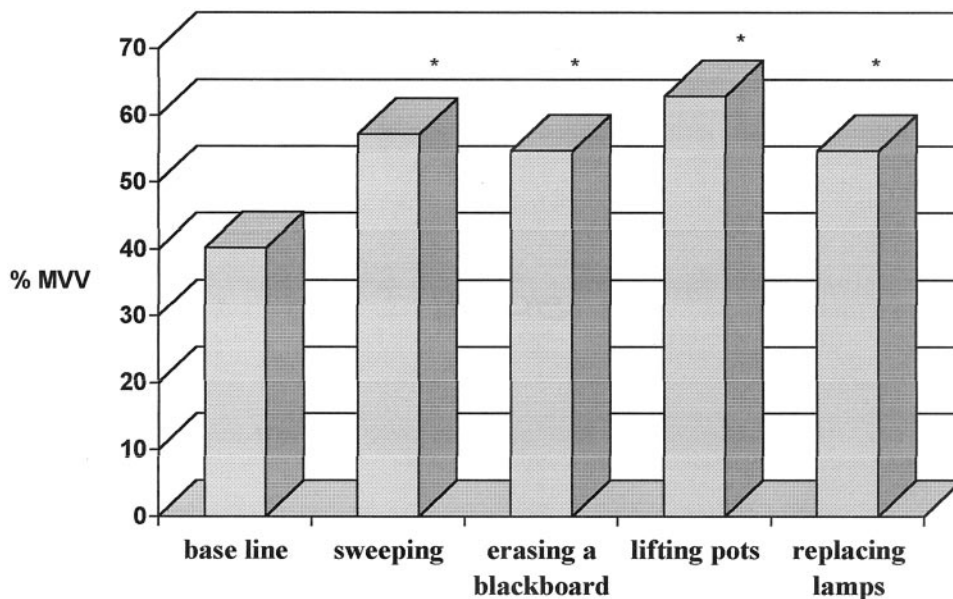


FIGURE 2. Comparison of the means of \dot{V}_E in percentage of MVV obtained during the performance of four ADLs in nine patients with COPD. * = $p < 0.05$ difference significantly different from baseline.

The increases in $\dot{V}O_2$ and \dot{V}_E observed during the execution of ADLs were more intense in sweeping the floor and pot-lifting activities. On the basis of published reports,^{3,5,14,16} we were expecting a stag-

gered increase in the ventilatory and metabolic demands in the activities that mostly use the muscles of the scapular belt. In this case, there should be a progressive increase in these variables, according to

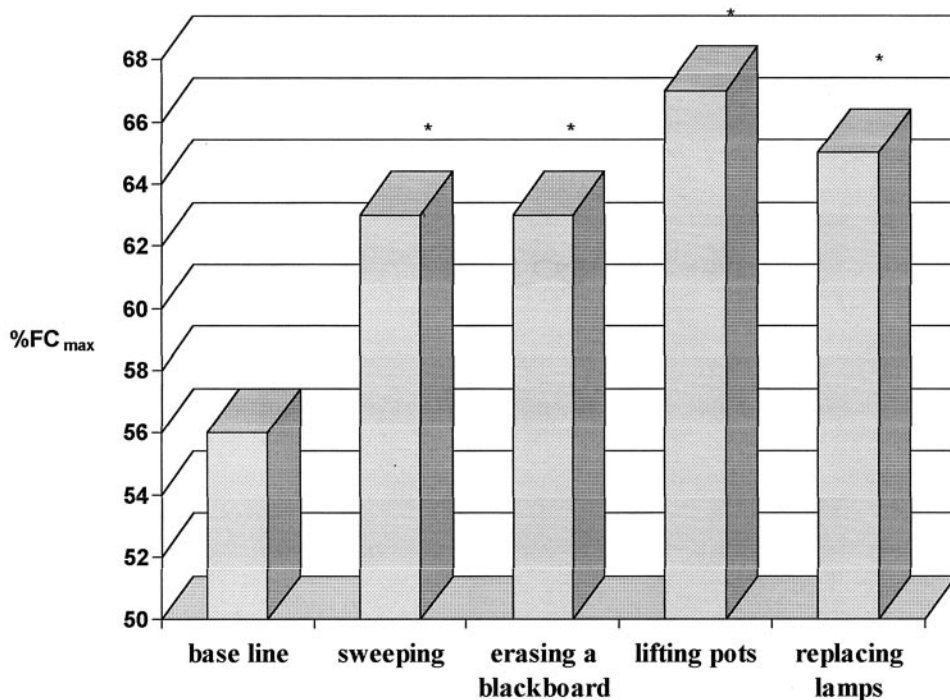


FIGURE 3. Comparison of the means of HR in percentage of HR_{max} obtained during the performance of four ADLs in nine patients with COPD. * = $p < 0.05$ difference significantly different from baseline.

the muscles used. So, our expectations, when the exercises were designed, were that the progressive demand for muscle usage would go from sweeping the floor to erasing a blackboard, changing bulbs, and lifting pots. Although this expected progression in metabolic and ventilatory demand did not occur, the sensation of dyspnea according to the Borg scale was higher in the activities involving changing bulbs and lifting pots (Table 4).

Another way of looking at the energy expenditure during the accomplishment of the tasks assigned to our patients is the measurement of oxygen pulse, which reflects the amount of oxygen extracted by the tissues of the body from the oxygen carried in each stroke volume.¹¹ We can see in Table 3 that the oxygen pulse increased in all four exercises, being higher for sweeping the floor and lifting pots, following the same trend that happened with the percentage of $\dot{V}O_2/\dot{V}O_{2max}$, $\dot{V}E/MVV$, and HR/HR_{max} .

The high Borg values seen in two activities may be explained by three factors: (1) lifting pots required a great deal of physical effort by the patients, as it involved a wide amplitude of upper limb movements particularly of the shoulders; the Valsalva maneuver was occasionally observed; (2) changing bulbs is a complex activity because, in addition to requiring the simultaneously elevated and unsupported upper limbs, it also requires a fine motor coordination of the hand; and (3) the upper limbs were maintained elevated and unsupported throughout the execution of the task, requiring the active participation of scapular belt muscles to maintain the activity. Our clinical experience has shown that activities requiring a higher level of concentration lead patients with COPD to engage in short periods of apnea during these activities, as also demonstrated by Tangri and Wolf.¹ The Borg measurement measures either the perception of effort by any muscle group or degree of dyspnea, being sometimes difficult for a patient to determine the degree.

It is conceivable that sustained muscle tension decreases blood flow. For the diaphragm muscle, blood flow may progressively decrease and approach zero at 75% of maximum transdiaphragmatic pressures.¹⁷ The same effect has been also described for active muscles of the forearm during hand grip contractions, suggesting that IM pressure during contraction may restrict its blood flow with a tension > 70% of the maximal voluntary contraction.¹⁸

That being the case, a sustained forearm muscle effort would decrease the arm blood flow and cause muscle fatigue, shortening the length of time for any arm activity. Older studies had already shown that exercises with the arms increase the sympathetic tone¹⁹ and lactate concentration, suggesting that working in a position that keeps the arm muscles under high tension may decrease their blood flow.²⁰ The increase in adrenergic vasomotor tone during exercise results in the constriction of the vessels and this response seems to be more pronounced in small muscle groups, as the arms.²¹ Alternate movements relax the muscle and allow restoration of blood flow and washing out the lactate, increasing the endurance time and somewhat decreasing the perception of effort used. It is interesting to notice that the activity of replacing lamps, despite having the lowest average $\dot{V}O_2$, presented a Borg index as high as lifting pots that presented the highest $\dot{V}O_2$. Replacing lamps kept the arms sustained constantly in an elevated position and may have impaired the blood flow to the muscles, leading to a precocious fatigue. Besides the decreasing of blood flow to the arms due to the arm muscle contractions, it has been speculated that in patients with COPD, the blood flow to peripheral muscles and the oxygen extraction during exercise may also be limited by a redistribution of cardiac output and oxygen from the lower limb-exercising muscles to the ventilatory muscles, in order to keep high ventilation.²² Our patients reached high ventilation to accomplish their tasks and blood flow may have been "stolen" from the arm muscles and redistributed to the ventilatory muscles, contributing to the fatigue of the arm muscles and expressed by the high Borg index.

The other two activities presented lower values on the Borg scale. We believe that this was due to the fact that during the sweeping activity the upper limbs were kept lowered and supported, not requiring a massive usage of the scapular belt muscles, although $\dot{V}O_2$ and $\dot{V}E$ were high. The blackboard-erasing activity required the arm to be kept elevated and unsupported, but in this activity switching arms was permitted in the case that the patient felt pain or fatigued. The dyspnea reported by the patients supports the literature findings that point out that the performance of patients with COPD of activities involving the upper extremity of the body may displace the respiratory functions of the scapular belt muscles to a more antigravitational func-

Table 4—Results of Borg Scale for Perception of Dyspnea During the ADLs in Nine Patients With COPD*

Patient No.	Sweeping the Floor	Erasing a Blackboard	Lifting Pots	Replacing Lamps
1	4	4	7	7
2	2	2	4	4
3	1	1	2	2
4	1	2	3	2
5	1	1	7	3
6	2	3	4	5
7	2	3	4	4
8	0.5	1	3	3
9	0.5	1	2	2

*Data are presented as No.

tion, increasing the work done by the diaphragm and the ventilatory demand.^{3,4,14}

Borg²³ related many different kinds of person-by-situation interactions, meaning that there may be different individualized responses to the same stimuli. We observed a large variation in the Borg index among our patients, but this has also been reported by others.^{24,25} Dyspnea is a feeling based on several factors including past experiences, social and cultural backgrounds, and even the emotional gain the person may achieve from it. These data are shown in Table 4.

The $\dot{V}O_2$ max values were not measured in our patients, as they were too limited in their physical conditions and expressed that they would not like to undergo maximal exercise testing on the treadmill. In fact, we did measure the $\dot{V}O_2$ max in a few patients, but the tests were not reproducible; in addition, the patients felt very tired and were afraid to take another test. The use of an estimated $\dot{V}O_2$ max has also been used by others.^{26,27}

Patients were left free to choose their own rhythm (frequency of repetition) for each ADL test, as we wanted to measure their ventilatory and metabolic demand, as close as possible as to how they would do it out in the real world. The performance of two tests on different days with our patients with COPD and normal subjects showed that metabolic and ventilatory evaluation during ADLs is reproducible and easy to execute, as already shown by Belman et al²⁸ and Marciniuk et al.²⁹

In summary, the data obtained from patients with moderate-to-severe COPD during the performance of four ADLs using the upper limbs permits us to conclude the following: (1) the high $\dot{V}O_2/\dot{V}O_2$ max ratio justifies the excessive fatigue reported by these patients, and (2) the high $\dot{V}E/MVV$ ratio explains the increased perception of dyspnea reported by these patients.

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