Objective: To assess the reliability of maximal inspiratory pressure (PImax) and maximal expiratory pressure (PEmax) in subjects with multiple sclerosis (MS) and healthy control subjects by identifying the number of testing sessions and the number of measurements needed in a single testing session to obtain consistent, reproducible results.

Design: A descriptive, comparative design with repeated measures was used.

Setting: Four sets of 10 PImax and 10 PEmax measurements were obtained over a 4-week period from MS subjects in their homes. The same measurements were obtained from healthy control subjects in a private setting.

Subjects: Seventy-two MS patients and 61 healthy control subjects participated in the study.

Measurement: PImax and PEmax values were obtained by using previously published methods.

Results: Mean PEmax and PImax values for MS patients differed over the first three of the four testing sessions. By contrast, mean PEmax and PImax values for healthy control subjects differed only when the first session values were compared with values from the last three sessions. For MS patients, PEmax and PImax increased between the first and 10th trial during the first testing session, but not during the subsequent three sessions.

Conclusions: The results of this study suggest that several practice sessions should be provided in order to obtain reliable PEmax and PImax values in persons with MS. At least one practice session should be provided for healthy control subjects before identifying a baseline.

Key words: maximal respiratory pressures; multiple sclerosis; respiratory muscle strength

Abbreviations: ANOVA = analysis of variance; MS = multiple sclerosis; PEmax = maximal expiratory pressure; PImax = maximal inspiratory pressure

Maximal respiratory pressures are used to assess both the strength of the inspiratory and expiratory muscles and the outcome of interventions designed to increase the strength of those muscles. Maximal respiratory pressures, noninvasive measures of inspiratory and expiratory muscle strength, have also been used to document the effects of pulmonary disease,1–3 neurologic disorders,4–6 and aging7 on respiratory muscle strength. The findings of a number of studies have suggested that varying values of maximal inspiratory pressure (PImax) and maximal expiratory pressure (PEmax) will occur based on the number of times a patient attempts the maneuver, the degree of fatigue generated by the repeated attempts at the maneuver, and a learning or mastery effect.3,7

Several disease-related changes associated with multiple sclerosis (MS) have the potential to affect measurement of maximal respiratory pressures; these include systemic fatigue, muscle spasticity, incoordination of the respiratory muscles, upper extremity weakness, bulbar symptoms, and weakness of the facial muscles. Studies of measurement of inspiratory and expiratory muscle strength in other neurologic disorders have not addressed the number of trials in a testing session and number of sessions required to obtain reliable results.

The purpose of this study was to assess the reliability of measurement of PImax and PEmax in subjects with MS and in a group of healthy control subjects. This study identified the number of weekly testing sessions needed and the number of measurements needed in a single testing session to obtain reproducible results, and examined these in MS patients by level of fatigue, ambulatory status, and sex.
Materials and Methods

This descriptive, comparative study with repeated measures was designed to determine the number of testing sessions and number of measurements within a testing session needed by patients with MS and healthy control subjects to obtain reproducible results.

Subjects

A convenience sample of persons with clinically definite MS was recruited from the MS clinics of two university teaching hospitals and a chapter of the Multiple Sclerosis Society. A second sample of healthy control subjects was recruited from the student body, faculty, and staff of one of the universities to permit comparison of values of subjects with MS to those of healthy control subjects. Only persons naive to measurement of inspiratory and expiratory pressures were included in the study. To be eligible, subjects had to understand the procedures and be willing and able to give informed consent and to cooperate with the testing procedures. MS subjects were excluded if they reported an upper respiratory infection either in the last 2 weeks or during the study; were, or appeared to be, depressed; had fever; or were seeking treatment for an MS exacerbation. Control subjects were free of neurologic or pulmonary disease. The study was approved by the appropriate institutional committees on human research.

The sample included 72 MS patients and 61 healthy control subjects. Demographic characteristics of the two groups are summarized in Table 1. Ambulatory status of MS study subjects was categorized as ambulatory, ambulatory with assistance, and nonambulatory. Ambulatory status of MS subjects was used to compare values of subjects with MS to those of healthy control subjects. Only persons naive to measurement of inspiratory and expiratory pressures were included in the study. To be eligible, subjects had to understand the procedures and be willing and able to give informed consent and to cooperate with the testing procedures. MS subjects were excluded if they reported an upper respiratory infection either in the last 2 weeks or during the study; were, or appeared to be, depressed; had fever; or were seeking treatment for an MS exacerbation. Control subjects were free of neurologic or pulmonary disease. The study was approved by the appropriate institutional committees on human research.

The sample included 72 MS patients and 61 healthy control subjects. Demographic characteristics of the two groups are summarized in Table 1. Ambulatory status of MS subjects was categorized as ambulatory, ambulatory with assistance, and nonambulatory. Ambulatory status of MS study subjects ranged from completely ambulatory with no assistance required to nonambulatory and requiring a wheelchair or motorized scooter to move from place to place. Those requiring assistive devices used a cane, crutches, or a walker for ambulation. Data on ambulatory status are missing for five subjects.

Measures

Maximal Static Respiratory Pressures: Maximal static respiratory pressures (P_{max} and P_{min}) were obtained, as described by Black and Hyatt. P_{max} is the maximal negative pressure measured at the mouth after complete exhalation to residual volume followed by a single sustained maximal inspiratory effort from that lung volume against an occluded airway. P_{min} is the maximal positive pressure measured at the mouth after inhalation to total lung capacity followed by a maximal expiratory effort from that lung volume against an occluded airway. These measurements reflect the strength of the inspiratory and expiratory muscles, respectively.

P_{max} and P_{min} were measured with a 200-cm magnehelic pressure gauge (No. 2000; Dwyer Instruments, Inc; Michigan City, IN). The pressure gauge measures pressures from 0 to ±200 cm H_2O in increments of 5 cm H_2O. Tubing 1 inch in diameter was used to connect the gauge to a three-way valve (No. 21043; Collins/Cybermedic; Braintree, MA) and the three-way valve to a plastic unflanged mouthpiece, 2.7 cm in diameter. One arm of the three-way valve was connected by tubing to the mouthpiece, the second arm was connected to the gauge, and the third arm was open to room air. A leak was created in the system with a 16-gauge needle to prevent generation of spuriously high pressures by the buccal muscles and to assist subjects in maintaining an open glottis during the measurements. Use of the three-way valve permitted subjects to position and seal the mouthpiece before the maneuver was performed, thus reducing technical measurement errors observed in some MS patients. Such errors are associated with tremor, lack of hand coordination, upper extremity weakness, or facial muscle weakness. Measurements were obtained with subjects seated and wearing a nose clamp. Subjects were permitted to hold the mouthpiece to position it comfortably and to hold their cheeks if necessary, although none elected to do so. A minimum rest period of 90 s was provided between measurements. Subjects were coached and encouraged during the measurements to achieve the highest values possible.

Calibration Technique: The measurement device was calibrated with low-, medium-, and high-range pressures generated by one investigator. This calibration produced identical values obtained simultaneously on the magnehelic pressure gauge and a mercury manometer. Prior to testing each subject, the testing device was calibrated to zero.

Protocol: With the three-way valve open to room air, the mouthpiece was inserted in the subjects’ mouths and subjects were asked to form a seal around the mouthpiece with their lips. For P_{max}, subjects were asked to inhale to total lung capacity (obtained by having subjects fill their lungs by taking as deep a breath as possible); the three-way valve was then turned to the closed position (connected to the gauge), and subjects were instructed to exhale with their maximal expiratory effort, producing a single expiratory effort. For P_{min}, subjects were asked to exhale to residual volume (obtained by having subjects empty their lungs by exhaling as much as possible), the three-way valve was then turned to the closed position (connected to the gauge), and subjects were instructed to inhale with their maximal inspiratory effort, producing a single inspiratory effort. For measurements to be considered technically acceptable, there could be no audible air leak around the mouthpiece detected by the investigator or reported by the subject, the subject had to report a successful effort, and pressure had to be maintained for at least 1 second.

P_{max} measurements were obtained before P_{min} measure-

Table 1—Demographic Characteristics of Sample by Groups

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>MS Patients (n = 72)</th>
<th>Control Subjects (n = 61)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>44.8 ± 10.0</td>
<td>35.2 ± 11.6</td>
</tr>
<tr>
<td>Range</td>
<td>23–74</td>
<td>20–65</td>
</tr>
<tr>
<td>Sex, M/F</td>
<td>25/47</td>
<td>9/52</td>
</tr>
<tr>
<td>Smoking history</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoked</td>
<td>21</td>
<td>34</td>
</tr>
<tr>
<td>Previous smoker</td>
<td>34</td>
<td>19</td>
</tr>
<tr>
<td>Current smoker</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>Pack-years (previous or current smokers) (n = 50)</td>
<td>23.9 ± 23.3</td>
<td>15.9 ± 18.6</td>
</tr>
<tr>
<td>Range</td>
<td>&lt; 1–120</td>
<td>&lt; 1–67.5</td>
</tr>
<tr>
<td>Ambulatory status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambulatory</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Ambulatory with assistance</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Nonambulatory</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Time since onset of MS symptoms, yr</td>
<td>13.1 ± 7.6</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>1.5–32</td>
<td></td>
</tr>
<tr>
<td>Time since MS diagnosed, yr</td>
<td>9.3 ± 6.5</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>&lt; 1–26</td>
<td></td>
</tr>
</tbody>
</table>
ments in all subjects because of previous data indicating that expiratory muscles are more impaired in persons with MS than inspiratory muscles, and because of our desire to minimize the effects of more fatiguing measurements of inspiratory pressures on expiratory measurements. P_{Imax} and P_{Emax} measurements were repeated a maximum of 10 times; fewer than 10 measurements were taken if the subject reported being unable to continue because of fatigue or if two consecutive pressures decreased 10 cm H$_2$O or more from the maximum pressure obtained previously by that subject after three technically acceptable measurements. Subjects were tested four times: the initial testing period was followed by repeat testing 1, 2, and 3 weeks later. A maximum of 10 P_{Imax} and 10 P_{Emax} measurements were obtained during each session. The number of testing sessions (four sessions over 4 weeks) was selected because previous studies have shown that maximum values generally have been reached by the third session and plateaued by the fourth session.

Level of Fatigue: Prior to and following completion of the testing, all subjects were asked to indicate their level of fatigue on a visual analog scale (10-cm horizontal line), with anchors of “no fatigue” (scored as 0) and “severe fatigue” (scored as 10). Subjects indicated their level of fatigue by making a mark at the point on the horizontal line that best reflected their systemic fatigue level. Ratings of fatigue on the 10-cm visual analog scale were categorized as low (0 to 3.3), moderate (3.4 to 6.6), or high (>6.6). In pilot work, MS patients have been able to distinguish between their fatigue levels before and after testing and from one session to the next. This method has been used in other studies to assess the degree of fatigue experienced by patients with MS.

All MS subjects were tested in their homes to minimize the inconvenience and systemic MS-related fatigue resulting from efforts of traveling to the MS clinic or the researcher’s office. The control subjects were tested in a private office. For each subject, testing was conducted in the same setting and at the same time each day to minimize the effects of late afternoon fatigue reported in MS. Subjects were asked not to modify their activities or level of exercise during the course of their participation in the study; they were asked to avoid any extremely fatiguing activities the day before and day of testing.

Statistical Analysis

Descriptive statistics were used to describe the sample. P_{Imax} and P_{Emax} values over the four testing sessions and within each session were analyzed by repeated measures analysis of variance (ANOVA) to identify changes in values over the course of the four sessions and over the 10 measurements in each session; Scheffe post-hoc analyses were conducted to identify specific differences between sessions and between measurements within sessions (p < 0.05). Two-factor repeated measures ANOVA was used to examine differences in the number of measurements within sessions by categories of fatigue, ambulatory status, and sex. Paired t tests were used to compare pre- and post-testing fatigue scores. Although absolute values (cm H$_2$O) and percent of predicted values of maximal respiratory pressures were calculated, results presented here are based on the prediction equations of Black and Hyatt.

RESULTS

Number of Testing Sessions

The means of 10 P_{Imax} and 10 P_{Emax} values of the four separate testing sessions were calculated for the MS patient group and the healthy control group (Table 2). Mean P_{Emax} values in MS patients differed by testing session [F (3, 71) = 15.513; p = 0.0001] with the following specific differences detected by post-hoc analyses: session 1 vs 3, 1 vs 4, 2 vs 3, and 2 vs 4. Mean P_{Imax} values in MS patients also differed by testing session [F (3, 71) = 24.91; p = 0.0001]. Specific differences were detected by post-hoc analyses when the first session’s mean was compared with those from the other three testing sessions and when the second and third sessions’ mean values were compared (1 vs 2, 3, and 4; 2 vs 3).

P_{Emax} values in healthy control subjects differed by testing session [F (3, 60) = 10.18; p = 0.0001]; post-hoc analyses indicated that differences were detected only when the first session mean P_{Emax} was compared with values obtained in the other three testing sessions (1 vs 2, 3, and 4). Differences by testing session (1 vs 2, 3, and 4; 2 vs 4) were identified for P_{Emax} values in healthy control subjects [F (3, 60) = 34.693; p = 0.0001].

These results indicate that two practice sessions are needed for MS patients to produce reliable P_{Emax} and P_{Imax} values by the third testing session. Healthy control subjects needed one practice in order to obtain reliable P_{Emax} and P_{Imax} values by the second session.

Number of Measurements Within a Testing Session

The mean values of each of the 10 measurements of P_{Emax} and P_{Imax} in each of the four testing sessions are presented in Table 2.

Table 2—P_{Emax} and P_{Imax} at Four Testing Sessions in MS Patients and Healthy Control Subjects*

<table>
<thead>
<tr>
<th>Group Data</th>
<th>Session 1</th>
<th>Session 2</th>
<th>Session 3</th>
<th>Session 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS group (n = 72)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P_{Emax}, % predicted</td>
<td>41.1 ± 20.2</td>
<td>42.7 ± 20.4</td>
<td>45.7 ± 21.6</td>
<td>45.6 ± 20.8</td>
</tr>
<tr>
<td>P_{Imax}, % predicted</td>
<td>61.0 ± 32.4</td>
<td>65.8 ± 32.6</td>
<td>70.0 ± 31.3</td>
<td>72.3 ± 32.5</td>
</tr>
<tr>
<td>Control group (n = 61)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P_{Emax}, % predicted</td>
<td>70.3 ± 14.9</td>
<td>73.7 ± 14.8</td>
<td>74.5 ± 15.4</td>
<td>74.6 ± 16.0</td>
</tr>
<tr>
<td>P_{Imax}, % predicted</td>
<td>101.7 ± 31.8</td>
<td>112.0 ± 29.3</td>
<td>115.2 ± 27.5</td>
<td>118.9 ± 28.7</td>
</tr>
</tbody>
</table>

*Data presented as mean ± SD.
sessions were calculated for the two groups separately (Fig 1) to determine the number of measurements within each session needed for MS patients and healthy controls to obtain consistent values. In MS patients, significant differences were detected between the 10 values of Pe\text{max} obtained in the first testing session ["within-subject" $F(9, 71) = 11.661; p = 0.0001$]. Post hoc analyses demonstrated differences when the first and second Pe\text{max} values were compared with other values in the first testing session. No significant differences were found among the 10 Pe\text{max} measurements obtained in any of the remaining three testing sessions. In MS patients, the only differences in Pt\text{max} values within a testing session occurred during the first testing session [within-subject $F(9, 71) = 10.355; p = 0.0001$] when the first four values in the first testing session were compared with values obtained later in that session.

In control subjects, differences were detected among the 10 values of Pe\text{max} obtained in each of four testing sessions. In the first testing session, differences were identified when the first three values were compared with the later values in that session [within-subject $F(9, 60) = 9.1; p = 0.0001$]. In the second, third, and fourth testing sessions, differences were detected when the first value or the first and second values were compared with the last values in the session.

Significant differences were found for healthy control subjects’ Pt\text{max} values when the first three Pt\text{max} values of the first testing session were compared with values obtained later in that session [within-subject $F(9, 60) = 22.7; p = 0.0001$]. In the second testing session, the first and second values differed when compared with the fifth through 10th values and the ninth and 10th values, respectively. In the third testing session, no significant differences among measurements were found. In the fourth testing session, the only significant difference was between the second and 10th values.

Three technically correct measurements in the third testing session are needed to obtain three reliable Pt\text{max} and Pe\text{max} values in MS patients. In healthy control subjects, five technically correct values in the second testing session are needed to obtain three reproducible values. Because the values of the first few measurements of Pe\text{max} and Pt\text{max} differed from later measurements in MS patients’ first two testing sessions and in all four testing sessions, differences were detected when the first value or the first and second values were compared with the last values in the session.

Figure 1. Means and SEMs for 10 Pe\text{max} and 10 Pt\text{max} values, obtained in each of four testing sessions, for MS patients and healthy control subjects. Note differences in scale of measurements on vertical axes. ■ = mean values for first testing session; ▲ = mean values for second testing session; □ = mean values for third testing session; × = mean values for fourth testing session.

In the second, third, and fourth testing sessions, differences were detected when the first value or the first and second values were compared with the last values in the session.

Significant differences were found for healthy control subjects’ Pt\text{max} values when the first three Pt\text{max} values of the first testing session were compared with values obtained later in that session [within-subject $F(9, 60) = 22.7; p = 0.0001$]. In the second testing session, the first and second values differed when compared with the fifth through 10th values and the ninth and 10th values, respectively. In the third testing session, no significant differences among measurements were found. In the fourth testing session, the only significant difference was between the second and 10th values.

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In the second, third, and fourth testing sessions, differences were detected when the first value or the first and second values were compared with the last values in the session.
sessions for healthy control subjects, analyses were repeated on mean P\textsubscript{Emax} and P\textsubscript{Imax} values for each testing session after the first three P\textsubscript{Emax} and P\textsubscript{Imax} values obtained in each testing session were deleted. This was done to determine whether the number of testing sessions needed to obtain reliable results was a function of the differences demonstrated in the first few measurements obtained during testing sessions. Results of repeated measures ANOVA using the fourth through 10th values of each of the four testing sessions duplicated the results, demonstrating that two practice sessions were required by MS patients in order to obtain reliable P\textsubscript{Emax} and P\textsubscript{Imax} values by the third testing session, and one practice session was required by healthy control subjects to produce reliable P\textsubscript{Emax} and P\textsubscript{Imax} values by the second testing session.

Sex

No interactions between sex of MS patients and repeated measurements (four testing sessions) of P\textsubscript{Emax} or P\textsubscript{Imax} were detected by two-factor repeated measures ANOVA. No interactions between sex and number of measurements (10 measurements in each session) were detected in any of the four P\textsubscript{Emax} sessions. There was an interaction between sex and repeated measures of P\textsubscript{Imax} in the first testing session only \([F(1.9) = 2.016; p = 0.04]\).

Fatigue

MS patients’ ratings of their general level of fatigue before and immediately after testing were compared; patients rated their fatigue level as significantly greater after testing \([\text{paired } t \text{ test (68) } = 5.7; p = 0.0001]\). Ratings of fatigue did not differ across the four testing sessions. Analysis of P\textsubscript{Emax} and P\textsubscript{Imax} values by level of fatigue demonstrated no interaction between P\textsubscript{Emax} or P\textsubscript{Imax} values and fatigue level during the four testing sessions or with the 10 measurements obtained in each of the four testing sessions.

Ambulatory Status

Mean values of MS patients’ P\textsubscript{Emax} and P\textsubscript{Imax} differed by category of ambulatory status, with less disabled patients having higher values. While there are significant differences in P\textsubscript{Emax} \([F(2, 66) = 13.864; p = 0.0001]\) and P\textsubscript{Imax} \([F(2, 66) = 8.914; p = 0.0004]\) by ambulatory status, no interactions were detected between number of testing sessions or number of measurements within each testing session.

Discussion

Number of Testing Sessions

The findings of this study indicate that two practice sessions are required by MS patients and one practice session by healthy control subjects to obtain consistent P\textsubscript{Imax} and P\textsubscript{Emax} values by the third and the second testing sessions, respectively. These findings suggest a learning effect and are consistent with those of other researchers who have studied healthy control subjects and patients with pulmonary disease. They also suggest that learning takes longer in persons with MS than in healthy control subjects. Other researchers have demonstrated increases in values of P\textsubscript{Imax} and P\textsubscript{Emax} in both healthy subjects and COPD patients when repeated over a number of testing sessions.\(^7\)\(^1\) Fiz et al\(^1\) demonstrated that P\textsubscript{Imax} and P\textsubscript{Emax} increased substantially in healthy subjects when measures were repeated three times a day, 1 day a week for 6 consecutive weeks. Larson and colleagues\(^2\)\(^3\) demonstrated that the reproducibility of the P\textsubscript{Imax} measurements can be increased in normal subjects and those with COPD by providing practice sessions 1 week apart. They concluded that P\textsubscript{Imax} was reliable in COPD patients when a minimum of one practice session, and preferably two practice sessions 1 week apart, were provided.

Number of Measurements in a Single Testing Session

Three technically correct measurements in the third testing session were needed in MS patients and five measurements in the second testing session by healthy control subjects to obtain reproducible P\textsubscript{Imax} and P\textsubscript{Emax} values. The number of measurements needed to obtain the highest values of P\textsubscript{Imax} has been the subject of several studies. In one study, when healthy subjects performed P\textsubscript{Imax} tests 10 or more times, pressures were higher than those reported by other researchers who used only two and three measurements.\(^12\) Others have reported that in healthy young adults, the maximal value of P\textsubscript{Imax} was related to the number of trials carried out, with values continuing to increase up to 10 trials.\(^13\) In a study that examined the number of trials needed to obtain reproducible P\textsubscript{Imax} values in patients with chronic airflow limitation, subjects were asked to perform 20 P\textsubscript{Imax} maneuvers each separated by 30 to 40 s.\(^1\) A minimum of nine P\textsubscript{Imax} maneuvers were required to obtain reproducible P\textsubscript{Imax} values in inexperienced, untrained patients with chronic airflow limitation. In a study of elderly healthy subjects, six measurements of P\textsubscript{Imax} and P\textsubscript{Emax} were usually necessary to obtain three acceptable measurements in the healthy elderly.\(^7\) The increases in values that were ob-
tained with repeated measurements in these studies again suggest that learning may be important in the reproducibility of these measurements.

Because 10 PEmax and Pmax measurements were obtained in each of the four testing sessions in the present study, it is not known if learning or mastery could be achieved with fewer than 10 measurements in each session. To answer that question, another study would be necessary comparing results obtained after fewer than 10 measurements.

**Testing of Patients With Neurologic and Neuromuscular Disorders**

Although a number of researchers have examined maximal respiratory pressures in patients with neurologic and neuromuscular diseases and reported decreased values, no previous study has addressed the number of measurement efforts in a single testing session or the number of testing sessions needed to account for learning or mastery effect in these patients. The findings of this study suggest that patients with neurologic impairment may require at least two practice testing sessions, more than healthy control subjects require, to produce reliable values at the third testing session. These findings suggest that obtaining Pmax and PEmax values during a single session and recording only the highest value obtained in that session is likely to produce inaccurate results in persons with MS. MS subjects’ PEmax values reached a plateau by the third session with remarkably little difference between values from one measurement to the next in the third and fourth testing sessions; control subjects, on the other hand, continued to increase their values across the four testing sessions and across the 10 measurements within each testing session, a finding consistent with that of others.

Recent studies have shown that persons with MS experience respiratory muscle weakness earlier in the course of the disease than previously reported and that expiratory muscle weakness is more severe than inspiratory muscle weakness. When it is severe, expiratory muscle weakness in persons with MS may lead to a weak, ineffective cough and inability to clear the airway, leading to respiratory complications that have been and remain a common cause of morbidity and mortality in MS. Fatigue, so common and disabling in persons with MS, was expected to affect their PEmax and Pmax values. However, PEmax and Pmax values in MS patients did not differ by fatigue level and were not affected by fatigue level over multiple testing sessions or measurements within a session, even though most patients reported increased fatigue after testing. Ambulatory status did affect the number of measurements of PEmax needed, but only during the first testing session; thus, providing two practice sessions before obtaining the true baseline measurement should address this effect. Sex and fatigue level did not affect the number of testing sessions or the number of measurements within testing sessions required to obtain consistent results.

Of interest is that PEmax was less than expected in this study, even in healthy control subjects. Although the expiratory muscle weakness in persons with physical limitations due to MS may be attributed to deconditioning associated with lack of physical activity, the explanation for decreased PEmax in healthy control subjects, to 73.3% of predicted (norm ≥ 80% of predicted), is less obvious. Although normal Pmax and PEmax values were first published three decades ago and have been used by clinicians and researchers for more than 30 years, large variations in these values have been reported. Several authors have demonstrated values in healthy subjects to be higher than published norms and attribute these differences to a learning effect that can be demonstrated by requiring a greater number of repetitions of the measurements. By contrast, other authors have suggested that these norms may overestimate Pmax by as much as 15% and PEmax by a greater percentage. Methodologic differences, including variation in the mouthpiece used in studies, and a learning effect have been identified as two factors that may be responsible for these variations.

The selection of the Black and Hyatt standards for this study requires comment. The mouthpiece used enabled subjects with weakness of the cheeks to grasp the mouthpiece and make a tight seal with their lips. While previous data have shown that subjects develop greater pressures when using unflanged as opposed to flanged mouthpieces, the mouthpiece used here most closely resembled that used by Black and Hyatt (ie, without flanges). The fact that the data obtained with this mouthpiece were very similar to data previously collected in MS patients using the standard Black and Hyatt apparatus further supports use of these standards in this study.
CONCLUSION

Accurate periodic P_{imax} and P_{e,max} measurements are useful in identifying both the need for interventions directed toward respiratory muscle weakness in impaired MS subjects who are unable to participate in physical activity and strategies to preserve respiratory muscle strength in persons with MS. The results of this study suggest a learning effect as a factor that needs to be considered in P_{imax} and P_{e,max} measurement. Failure to take this learning effect into account may result in inaccurate assessments of respiratory muscle strength in healthy control subjects as well as in patients with pulmonary or neurologic disorders. If measures of P_{imax} and P_{e,max} are used to assess the effects of respiratory muscle training without first establishing an accurate baseline, increased values due to a learning effect could be incorrectly attributed to respiratory muscle training. Information obtained from this study will enable more accurate assessment of maximal respiratory pressures (P_{imax} and P_{e,max}) in persons with MS and other neurologic disorders.

REFERENCES